ELECTROMECHANICAL components & systems DESIGN

DECEMBER 1960

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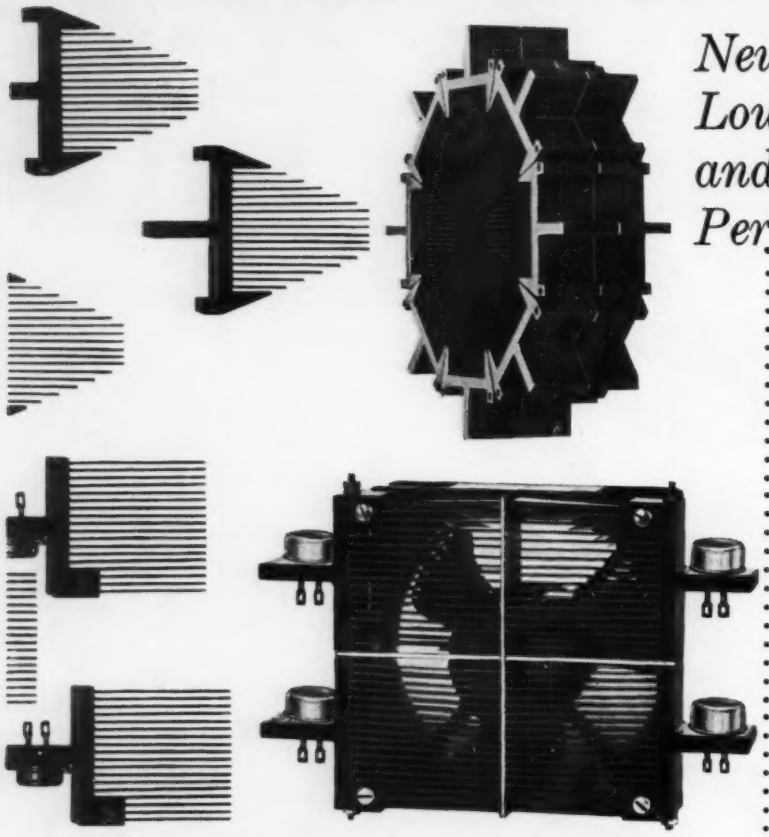

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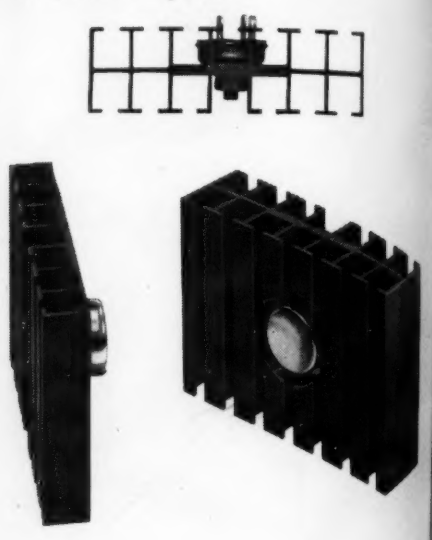

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The Sourcebook of Design Ideas in Applied Electromechanics

DECEMBER 1960 • VOL. 4 NO. 12

Contents

Components Design

14 PHOTOELECTRIC TEMPERATURE CONTROL
Operation similar to an optical pyrometer

15 COMPONENT HOLDING AND COOLING
A sometime overlooked factor in designing for reliability

16 MECHANICAL LOW-FREQUENCY GENERATOR
Versatile cam design generates many arbitrary waveforms

20 SELF-LUBRICATING BEARING
Plastic construction provides high load-carrying capacity

23 SILICON EPITAXIAL TRANSISTORS
Processing technique reduces collector resistance and switching time

Systems Design

26 NON-LINEAR ANALYSIS OF CONTROL LOOP FOR A STABILIZED MOUNT
"Torque picture" superimposed on phase plane allows prediction and control of responses

32 EXPLOSION SUPPRESSORS
Automatic system snuffs out accidental blasts

Design Time Saver

38 SELECTION OF PILOT LIGHTS BY LAMP TYPE

New Techniques

46 MICROMINIATURE CIRCUITRY
Thin film components for integrated circuits

Research

56 NEW THEORY FOR RUSTING OF IRON
Hydrogen ions from water vapor cause destructive reactions

Components Digest

58 DIGITAL VOLTMETERS—Components Digest 18
Sampling frequency, basic converter types, converter bandwidth, selection factors, commercial equipment

Departments

25 PRODUCTION AIDS

37 CONTRACTS

55 MATERIALS

76 NEW COMPONENTS FOR ELECTROMECHANICAL SYSTEMS

78 BOOK REVIEWS

80 NEW CATALOGS FOR YOUR LITERATURE FILE

81 PRODUCT INDEX

82 INDEX TO ADVERTISERS

84 DATA SHEETS FOR YOUR THREE-RING BINDER

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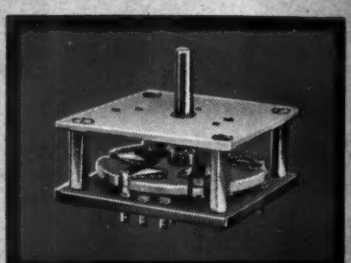

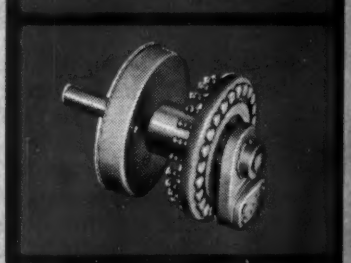

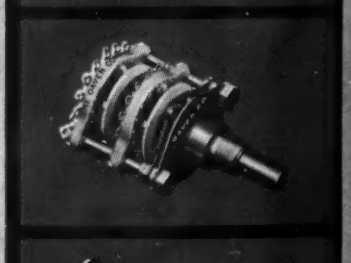

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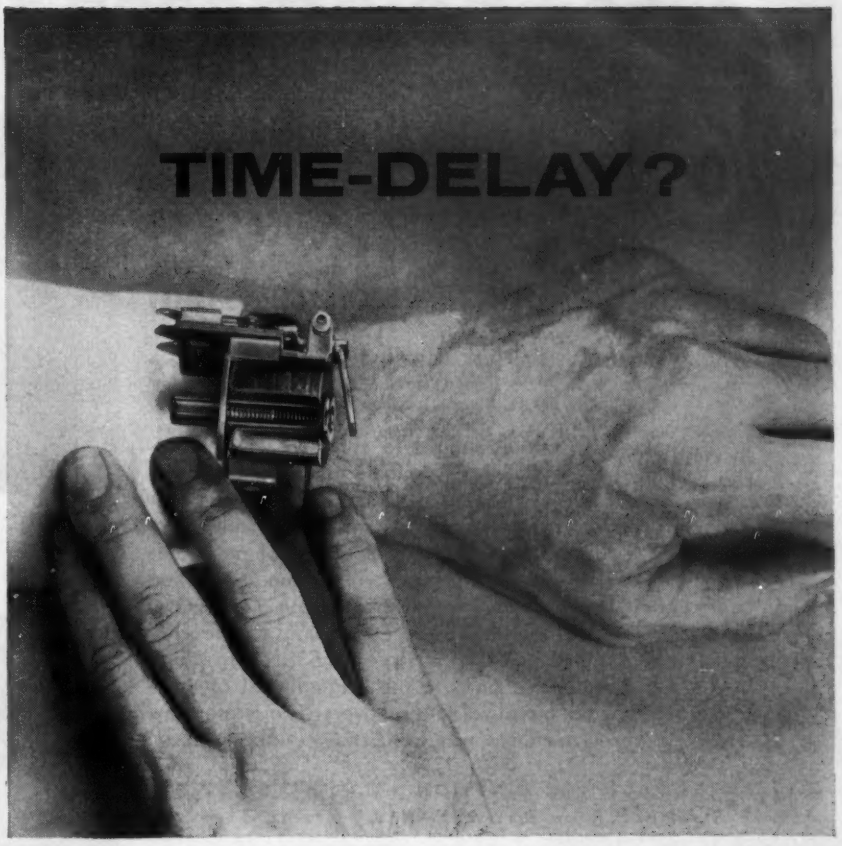

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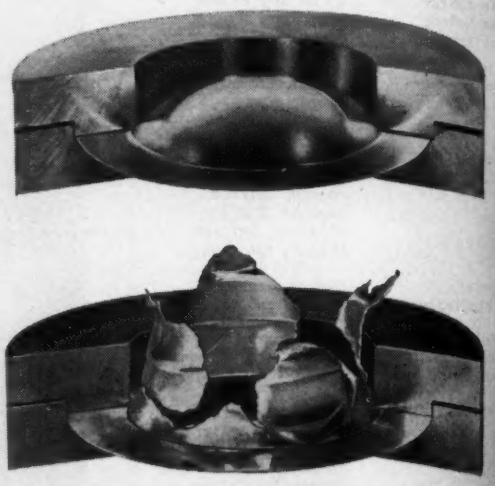

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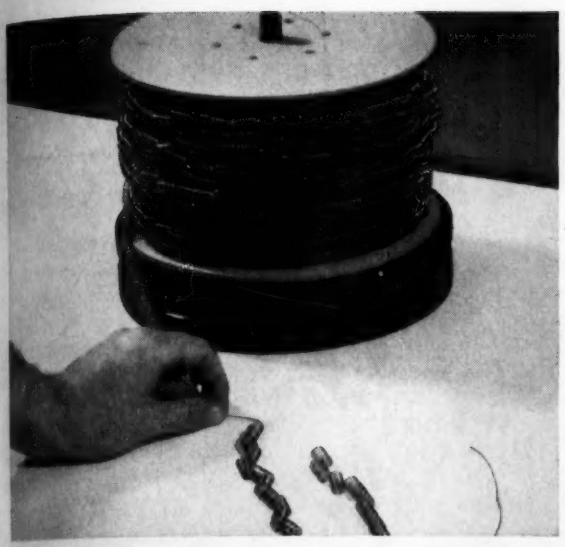

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PHOTOELECTRIC TEMPERATURE CONTROL

Operation Similar to an Optical Pyrometer

PyroTemp, a photoelectric temperature control developed by The Clark Controller Co., Cleveland, Ohio, is a temperature-limiting device for controlling industrial heating processes. The unit will control the temperature of moving parts on continuous strip, count heated work-pieces, control automatic quenching and control induction or resistance heaters.

PyroTemp functions by measuring infra-red radiation. No contact with the workpiece is required since the temperature is sensed from a distance. The pickup, with an infra-red sensitive photocell, is aimed at the heated surface. An amplifier, temperature-selection dial, and output relay is housed in a separate control unit. When the temperature exceeds that of the pre-set level, the relay operates. Because of the rapid response time of the lead-sulphide photocells, speed is limited only by the operating time of the output relay. Fig 1 illustrates the operation of Model PT-803.

For use where the minimum temperature to be controlled is 500 F or greater from an area of 0.125 sq. inches at a distance of 1 foot, Model PT-803 has a refined optical scanning system that can be focused at very small areas. Repetitive accuracy is ±1% at the lower end of the temperature range. Applications include delicate soldering operations where sufficient heat is necessary to obtain a good joint, but where excessive heat would damage or alter part structure.

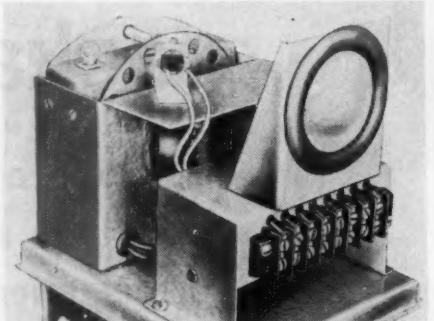

Fig 2 Pickup unit of Clark Controller's photoelectric temperature control. Physical contact with the workpiece is not necessary.

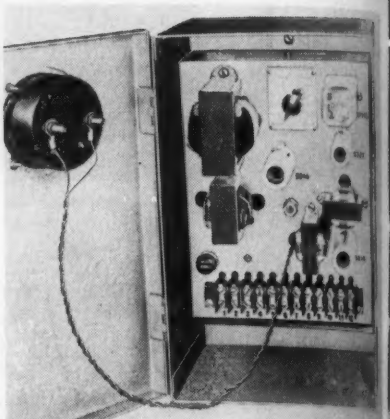

Fig 3 Control unit of Pyrotemp, a photoelectric temperature control.

Model PT-803 contains two units: A dust-proof pickup unit (Fig 2) that contains the focusing optical system, reference lamp, infra-red sensitive photocell, ball-bearing motor and aperture disc; the control unit (Fig 3) contains the amplifier, meter, thyratron-controlled output relay and adjustable-potentiometer level control.

Ambient operating temperature range for the control and pickup is 0 to 100 F. Power supply is 105-125 volts, 60 cycles. Current input is 0.35 ampere. The shortest signal required to operate the relay is 1/60th second and the maximum operating rate is 600 per minute.

A second model, PT-801, is for use where the minimum temperature to be controlled is 1000 F or greater from an area of 0.42 sq. inch at a distance of 1 foot. Repetitive acucracy is ±10% at the lower end of the temperature operating range but greater accuracy can be expected at higher temperatures.

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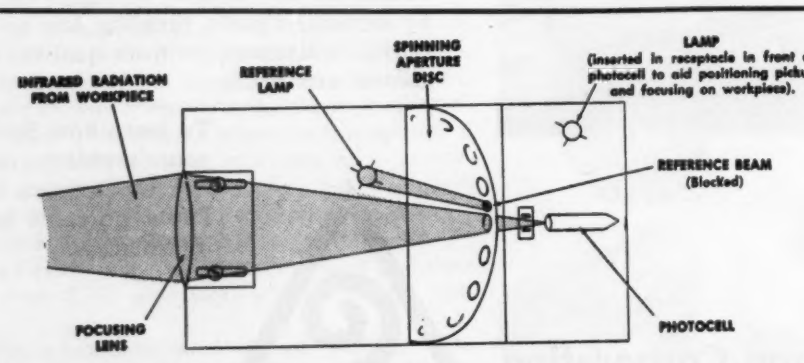
INFRARED RADIATION FROM WORKPIECE
REFERENCE LAMP
SPINNING APERTURE DISC
LAMP (Inserted in receptacle in front of photocell to aid positioning pickup and focusing on workpiece).
REFERENCE BEAM (Blocked)
FOCUSING LENS
PHOTOCELL

Fig 1 Model PT-803 works like an optical pyrometer with a photocell substituted for the human eye. Infrared radiation from the heated workpiece is focused on the moving apertures of a spinning disc and fall on a photocell whenever an aperture passes between the lens and photocell. A reference lamp is also focused on the spinning disc in such a way that "reference pulses" are generated as the photocell first sees the reference lamp and then sees the heated workpiece. The intensity of the reference lamp is varied by a potentiometer control and the output relay is energized when the radiation from the heated workpiece equals or exceeds the radiation from the reference lamp. Since photocell and amplifier work on the difference or equality of two signals, any drift in photocell sensitivity or amplifier gain has no effect on accuracy.

COMPONENT HOLDING AND COOLING

A Sometimes Overlooked Factor in Designing for Reliability

by Arthur F. Spear, Jr., *Chief Engineer, Atlee Corp., Woburn, Massachusetts*

Continued emphasis on reliability of components has focused increased attention not only on the structure and performance of the components themselves but on their immediate environment–allotted space in the system, position and means of fastening and holding, and facilities for cooling and protection from shock, vibration and related hazards.

Growing use of printed circuitry and modular type construction has served to intensify the need for fuse clips and small component holders, heat sinks, and related devices which will permit quick and easy insertion and withdrawal of small parts repeatedly without fracturing or losing their holding power. Replacement of such holding devices is inherently difficult in cramped quarters without damaging the protective coatings or structural integrity of the mounting board. It is therefore all the more important that these parts have long life and reliability.

The engineer would do well to look beyond the specification of conventional spring steel clips, particularly if he is designing for the missile and rocket field, for satellite equipment or airborne systems where reliability is a critical factor. Recent developments in metallurgy and heat treating techniques have contributed to a significant improvement in holding and cooling devices of beryllium copper–a material long known for its superior resistance to corrosion and fatigue, but until now, inordinately difficult to compound and fabricate with consistent and desirable characteristics.

Design details for spring steel clips are not applicable to beryllium copper without extensive modification of material thickness, of contour and conformation, of spring tension and other variables. Sympathetic resonance frequencies are different, requiring damping measures quite different from those of steel.

Perhaps the most common failure of conventional steel clips and holders is their tendency to fracture, either because of the flexing action of insertion and withdrawal, or more likely, from fatigue set up through sympathetic vibration. In most modern civil and military aircraft, the troublesome resonance range is from 1200 to 1500 cps. Even if fracture does not occur, vibration at these frequencies causes a pronounced loss of holding power, and in some cases will "walk" the component longitudinally out of the clip or holder.

The introduction of beryllium copper did not immediately yield the answer to the problem of fracturing; moreover it introduced additional difficulties of fatigue in the form of spring tension relaxation. Persistent research revealed that the cause of both phenomena lay in the heat treating, which permitted the metal to absorb minute quantities of hydrogen. The hydrogen embrittlement tended to concentrate at the surface, particularly in the radii. The shorter the radius, the greater the relative concentration of embrittlement.

While extensive experimentation continued with other non-ferrous metals and with various steel alloys, a major study of beryllium copper heat treating fulfilled most of the desired goals–as had been expected. Empirical testing of various wall thicknesses resulted in a choice of 0.016 inch as a standard gauge for all but the very large or the microminiature sizes. This material permitted specification of temper and platings which produced a finished product with a resonance frequency well above the specified spectrum limit of 2000 cps, while retaining all of the other needed characteristics.

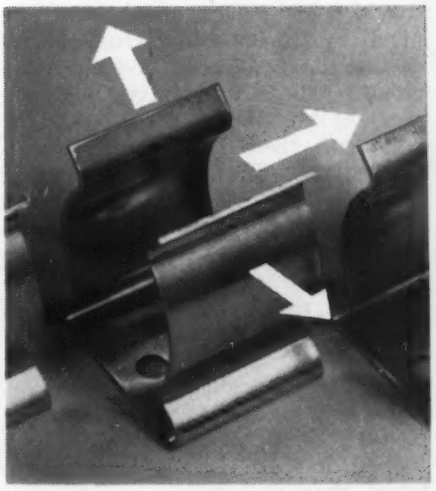

Fig 1 Atlee Corp's. beryllium copper tube holder for applications where reliable holding ability under extreme environments is required. The arrows show direction's test forces were applied.

The testing program included evaluations for holding power under impact and under steady-state acceleration, for holding power of the clips when subjected to a vibration environment up to 2000 cps before and after an insertion-withdrawal life test, and after exposure to 500°F for 15 minutes.

The impact and acceleration tests indicated no significant movement between the component and its holding clip after 50 g's impact or when subjected to 63½ g's acceleration. None of the clips broke, nor did any exhibit a resonance frequency below the specified limit. Fig 1 illustrates the planes in which the impact and acceleration

Force (lbs) Required to Slide Component Out of Holder (Based on 95% Confidence Level)

UNIT	SIZE	PLANE	DYNAMIC TEST PRIOR TO LIFE TEST	DURING LIFE TEST	DYNAMIC TEST AFTER LIFE TEST	DYNAMIC TEST AT HIGH TEMP.*
A	0.016	1	6.9±3.4	7.1±1.3	7.6±2.6	10.2±2.64
		2	8.9—4.5		9.1—2.5	....
B	0.016	1	4.4±3.6	2.6±0.7	4.2±2.4	4.0±1.74
		2	3.3—2.4		3.9—1.8	.....
C	0.014	1	6.1±2.6	5.2±1.9	5.1±2.0	5.9±1.86
		2	5.8—2.8		4.4—1.9	....

*The surface temperature of the clips was approximately 200° F at the start of the test and decreased to 95° F at 1100 cps. The surface temperature remained at 95° F throughout the conclusion of the test.

Four clips of each description were used in these tests. All clips were of silver plated beryllium copper. Two No. 2-56 screws tightened to 6 in.-lbs were used to hold each clip to the board during all tests.

tests were conducted. An essentially similar series of tests on representative samples of clips and holders supplied by three manufacturers were conducted by Bendix Aviation Corporation's Bendix products Div. (missiles) at Mishawaka, Indiana, and reported in their Engineering Reports 247 and 345. The results shown in the following tables illustrate the fact that these small devices are worthy subjects for continuing research and engineering development. Differences in performance are attributed primarily to differences in the heat treating techniques.

As miniaturization is developed, more and more emphasis will be placed on sophistication in holding and cooling devices. The dividing line between them and the bona fide component itself may become indistinct.

For some time to come, however, the independent holding and cooling devices must continue to improve to meet increasingly stringent demands. It behooves design and standards engineers to be aware of the demands that system performance requirements impose on them in selecting these devices from the wide variety available.

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WORTH FILING

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Properties of 32 commercial glasses, including several new varieties, are detailed including mechanical, electrical, thermal and viscous. The 16 page booklet also contains new sections on thermal expansion and optical properties. Temperature conversion chart is also included.

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Source: H. M. Harper Co.
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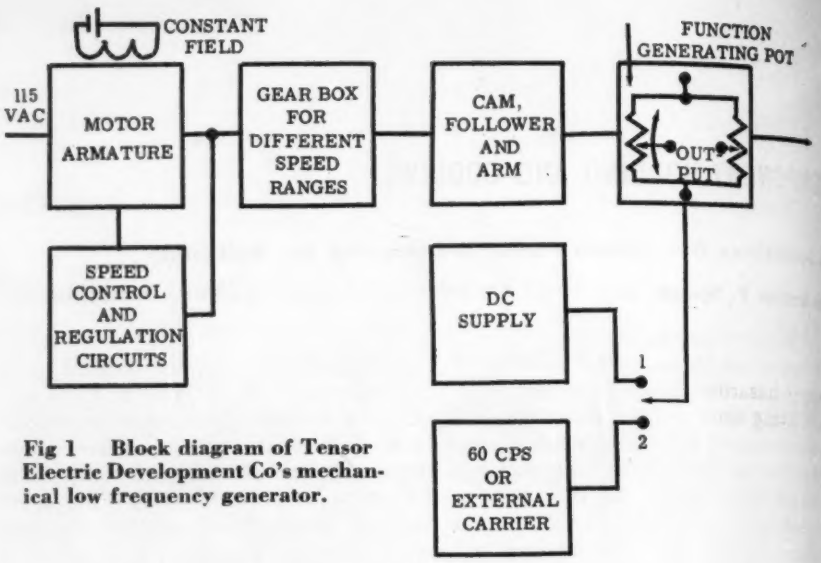


Fig 1 Block diagram of Tensor Electric Development Co's mechanical low frequency generator.

MECHANICAL LOW FREQUENCY GENERATOR

Versatile Cam Design Generates Many Arbitrary Waveforms

Low frequency (under 1 cps) waveform generators have conventionally used electronic circuitry (diode shaping networks) to produce sine, triangle and other waveforms. Mr. Bruce Erlichman of Tensor Electric Development Co., Brooklyn, N.Y. pointed out that the sophistication of these circuits has inevitably led to a high selling price and limited applications (in the sense that these generators produce only those waveforms for which the circuits have been designed). This consideration prompted his company to develop a generator that uses mechanical means for producing sine and triangle waveforms. By simply changing cams, many arbitrary waveforms can be generated and are available in a modulated suppressed carrier form (with externally supplied carrier or internal 60 cps carrier) at the front panel terminals for servo testing and experimentation. Mr. Erlichman reported that this generator costs less to produce than the conventional types.

Fig 1 shows a block diagram of the essential elements of the mechanical generator. The driving motor is a constant field excitation dc motor whose speed is variable from 600 to 6000 rpm. A feedback circuit using a tachometer, thyratron and phase shift network accomplishes speed control and regulation.

Covering 10,000 to 1 overall speed reduction range, four output shafts of the gear box reduce the motor speed by 10 to 1 in four steps so that the outputs are 60 to 6 rpm, 6 to 0.6 rpm, 0.6 to 0.06 rpm and 0.6 to 0.006 rpm. The gear box output drives a shaped, phenolic cam whose spring held follower arm is attached to a potentiometer. The angular position of the pot is proportional to the cam rise and fall so that if a dc voltage is applied to the pot, the output voltage is proportional to the function reproduced on the cam. Actually, the output is taken differentially to eliminate the dc component. If ac is applied to the pot, the output is a suppressed carrier (phase reversing) signal whose envelope is the desired function. Thus, the generator will produce a waveform proportional to the cam radius at frequencies of 10 to 1 cps, 1 to 0.1 cps, 0.1 to 0.01 cps and 0.01 to 0.001 cps.

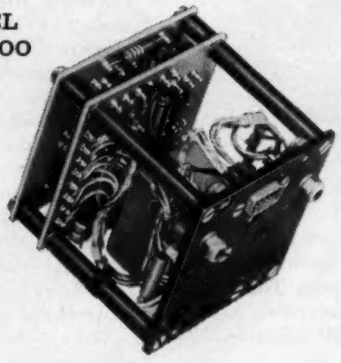
Torque builds up as the motor speed is stepped down. Therefore, it was first thought that regulation of the motor speed with torque would not be required. However, since a stiff spring holds the follower to the cam (necessary because of 10 cps upper limit in frequency), regulation was needed. With the regulation circuit used, a higher torque (occuring on that portion of the cam with a large pressure angle) tends to slow down the motor, thereby dropping the voltage out of the tachometer. This causes the thyratron grid voltage to become less negative, allowing the tube to breakdown earlier in the cycle and permitting more current to flow to the motor. Thus, the motor tends to pick up speed and re-establish initial conditions. The phase shift network of the regulation circuit allows greater control of the firing angle.

The design of the cam involved plotting the necessary function on polar coordinates, adding a constant to prevent negative radii and an analytical method for eliminating error due to cam follower moving in an arc rather than a straight line. A DPDT switch provides a square wave output for synchronous purposes.

Write No. 187 in Box on Inquiry Card

We welcome modifications to our standard Power Supply Line!

MODEL
2E30-100



military requirement

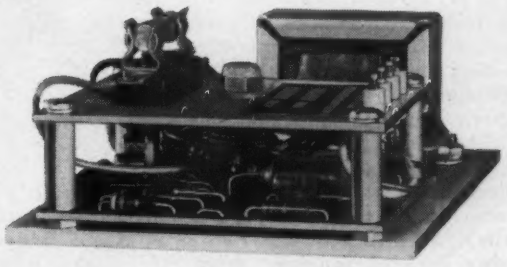
Polaris missile submarines are using this power supply in the precision servo system which drives and positions the navigational periscope. Developed by Nortronics, Norwood, Massachusetts, the system has proven very successful. The critical accuracy necessary for navigation required a very stable power supply.

Input:
115 volts ±10% 400 cps ±5%
Dual Output:
#1 +30 volts D.C. @ 100 ma
#2 −30 volts D.C. @ 100 ma
Line Regulation:
.05% for 105 to 125 volts input
Load Regulation:
.1% for 0 to full load
Ripple:
.1% peak to peak
Operating Temperature:
0 to +50°C
Storage Temperature:
−65 to +85°C
Dimensions:
3" x 2⅞" x 3⅜" high
Weight: 1#

Meets MIL-E-16400b (USN)
MIL-STD-242

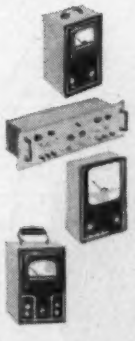
Modification of standard Minisource® Model M30-100

MODEL SM5-15



commercial application

A complete family of temperature indicating instruments and bridges, manufactured by RdF Corporation (formerly Arthur C. Ruge Associates) Hudson, New Hampshire, utilizes the SM5-15. Small and light enough to go into portable instruments with output measurements to within 2.5°F, it is precise and well regulated for use in a high accuracy temperature averaging wind tunnel system with output measurements to .1°F.



Input:
115 volts ±10% 60 to 400 cps.
Output:
+5 volts D.C. @ 15 ma
Line Regulation:
.1% for 105 to 125 volts input
Load Regulation:
.25% for 0 to full load
Ripple:
.1% peak to peak
Operating Temperature:
0 to +50°C
Storage Temperature:
−40 to +75°C
Dimensions:
5" x 3½" x 1½" deep
Weight: ¾#

Modification of standard Minisource® Model M5-50

These are typical examples of Elasco's flexibility in modifying the standard Minisource® line to customer requirements.

Write Now For Your Copy Of Catalog #960
Do Not Hesitate To Contact Us Regarding Your Requirements

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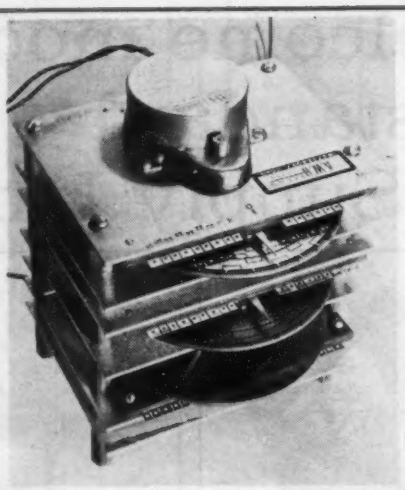
CIRCLE NO. 16 ON INQUIRY CARD

BINARY CODE GENERATORS

Versatile Combinations of Motor-Driven Printed Circuit Discs



Designed in response to the rapidly increasing demands of industry and the military for inexpensive devices which present accurate electrical output signals in digital coded form, binary time code devices, developed by A. W. Haydon, Waterbury, Conn., are basically shaft-position encoders. Analog data in the form of shaft-position angles are converted to a digital output represented by a coded pattern of electrical signals.

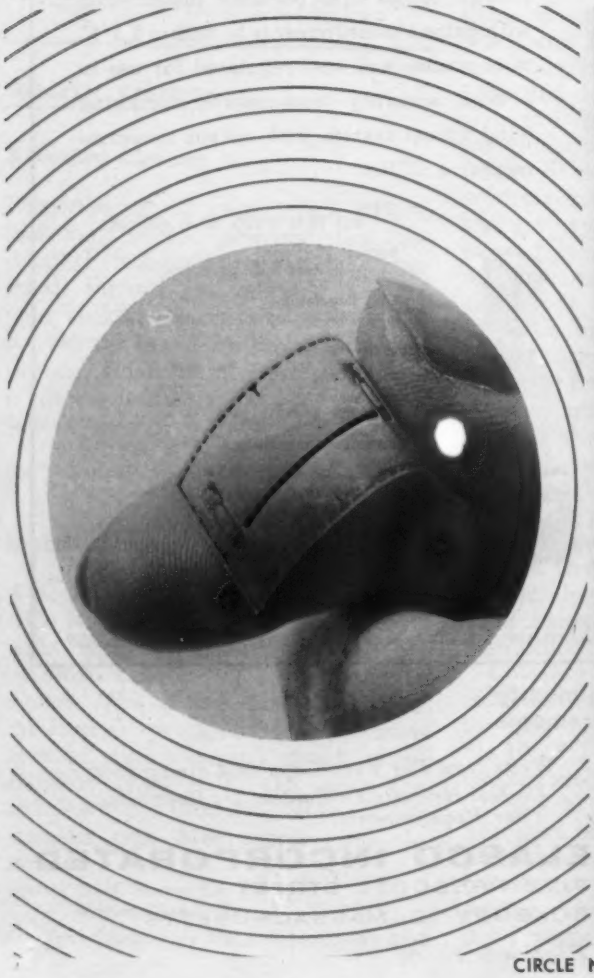
Although units presently in production are basically binary time coded, many types of output code (pure binary, excess three, gray or cyclic), as well as wide ranges of timing periods, different drive systems, a large selection of ac and dc timing motors or stepper motors and various types of control and accessory equipment can be combined to satisfy a wide variety of specific requirements.

Military version of the code generator consists of a synchronous motor driving two printed circuit code discs, with each circuit having a switching pattern representing 0 to 59 in decimal binary code. Together, they provide 3600 consecutive coded time periods through 59 minutes, 59 seconds, after which they recycle. Bidirectional external adjustment knobs permit resetting or presetting the circuits to coincide with reference times whether the unit is operating or not.

Another model of the A. W. Haydon binary encoders is a binary time digital master clock with an illuminated display which indicates time in minutes and seconds, up to 999 minutes. The unit provides positive synchronization between the master clock and slave clocks at all times. Binary time code signals are generated by motor-driven code discs within the master clock assembly, and these signals energize the digital readouts for both the master clock and any number of remote slave clocks. The desired display time (time remaining or countdown time) can be reset or preset by manually turning the set knobs on the front panel of the master clock. With the panel switch in the "internal" position, the clock will operate directly from 115 v. 60 cps power lines. With the switch in "external" position, it will operate from an external crystal controlled 60-pulse-per-minute pulse source.

Other design modifications provide an add or subtract function only, instead of the joint subtract and add function; allow operation on different power supplies; and include a method for presetting programmed functions at preselected times within the time range.

Write No. 193 in Box on Inquiry Card



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SEMICONDUCTOR STRAIN GAGE
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FEATURING
- Sensitivity—gage factor 130
- Easily bonded to all types of surfaces for military, industrial and space applications
- Integral terminal construction
- Superior signal-to-noise ratio
- Resistance—350
- Size: Element—⅜" x .020" Complete Gage—1" x ½"
- Radius of Curvature—½"
- Maximum Operating Strain—over 3000 microstrain

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MSI MICRO SYSTEMS INCORPORATED
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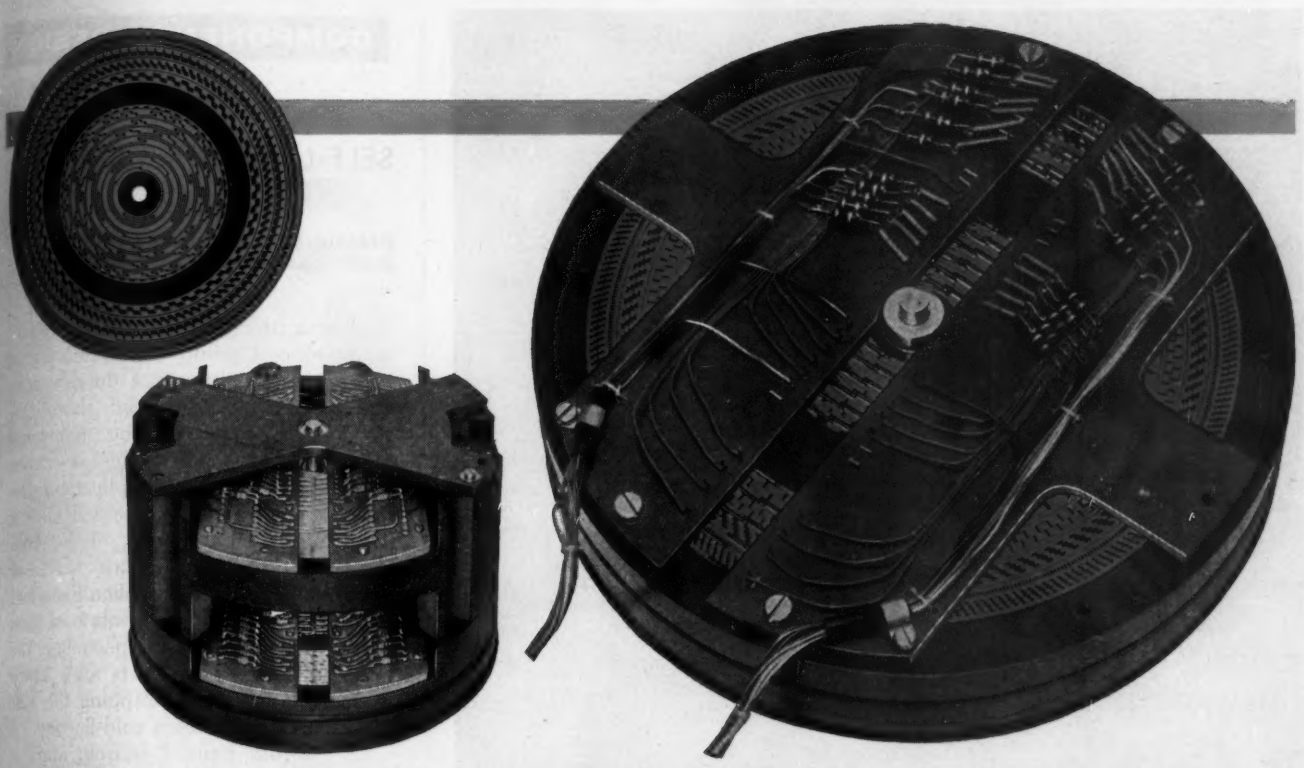
A Subsidiary of Electro-Optical Systems Inc.

CIRCLE NO. 17 ON INQUIRY CARD



Now Norden binary-coded decimal converters for commercial application

- **1000 count per turn**
- **self-contained logic**
- **self-selecting brushes**
- **continuous reading at high speeds**
- **several models in 4 2 2 1 code***

Norden offers a wide variety of binary-coded decimal shaft encoders for commercial applications. These encoders meet or surpass military specifications, and have patented, self-selecting V-brush logic.

Code disc patterns produce a totally unambiguous 8-4-2-1* binary decimal readout ranging from 2 to 6 decades. The units can be used for feeding high speed computers and servo systems . . . data logging, machine tool automation, test stands, flight check-out. Self-selecting V-scan increases reliability and life while saving space and reducing complexity and cost. Load carrying brushes never commutate. These are the only encoders that have provision for automatic self-checking gating devices for virtually 100% error monitoring.

*Several models are available in *4-2-2-1 CODE* which provides a nine's complement and makes available in a single encoder an increasing numerical count for both directions of shaft rotation.

MODEL NO.	TOTAL COUNT	REVOLUTIONS FOR FULL COUNT	ACCURACY (1 part in)
ADC-ST2-BCD	10^2	1	100
ADC-3-BCD	10^3	10	1,000
ADC-4-BCD	10^4	100	10,000
ADC-5-BCD	10^5	1,000	100,000
ADC-6-BCD	10^6	10,000	1,000,000
ADC-ST3-BCD	10^3	1	1,000
ADC-5-BCD-1000	10^5	100	100,000
ADC-3-36BCD	360	3.6	360
ADC-4-36BCD	3600	36	3,600
ADC-5-36BCD	36,000	360	36,000
ADC-6-36BCD	360,000	3,600	360,000
ADC-ST3-36BCD	360	1	360
BRL-5	360,000	1	360,000
ADC-ST2-BBCD*	10^2	1	100
ADC-3-BBCD*	10^3	10	1,000
ADC-4-BBCD*	10^4	100	10,000
ADC-5-BBCD*	10^5	1,000	100,000
ADC-6-BBCD*	10^6	10,000	1,000,000
ADC-3-36BBCD*	360	3.6	360
ADC-4-36BBCD*	3,600	36	3,600
ADC-5-36BBCD*	36,000	360	36,000
ADC-6-36BBCD*	360,000	3,600	360,000

Write Norden or call TRinity 4-6721 for complete specifications

NORDEN

NORDEN DIVISION
UNITED AIRCRAFT CORPORATION
MILFORD DEPARTMENT, WILEY STREET, MILFORD, CONNECTICUT

CIRCLE NO. 18 ON INQUIRY CARD

WHAT IF YOU GET NO WARNING UNDER VIBRATION?

Vibration is one of the cruelest enemies of pressure switches. The unit that performed so well in the lab can have its insides shaken apart when vibration hits a resonant frequency.

The only way to be assured of satisfactory performance is to run the pressure switch through tests that duplicate every known operating requirement.

Take Model 6885 shown at right. Integral vibration isolation between mounting bracket and switch body makes possible exceptional performance under shock and vibration. Its accuracy is ±4% under all conditions, including ambient temperatures ranging from −75°F to 250°F, as well as vibration at all frequencies through 2,000 cps. It weighs only 10 oz., measures 3⅜" to 4⅜".

Do it yourself. Take one of our Model 6885 units and run it through six weeks of testing as we did.

Or save six weeks by asking for our test data on a full line of pressure switches and choose the units that fit your needs best. Call Mr. Charles Colt at Consolidated Controls, Bethel, Conn. Phone Pioneer 3-6721.

Inches of Water to Hundreds of Atmospheres

Model 6885 shown above is one of more than 300 pressure switches available from Consolidated Controls for missile, aircraft and nuclear applications. Working pressures range from 10" of water to 10,000 psi at ambient temperatures from −65°F to 1000°F. Standard models for

- high vibration
- differential pressures
- hydraulic
- miniaturized applications
- high temperature

CONSOLIDATED CONTROLS CORPORATION

A Member of The Condec Group

BETHEL, CONNECTICUT
INGLEWOOD, CALIFORNIA

CIRCLE NO. 19 ON INQUIRY CARD

SELF-LUBRICATING BEARING

Plastic Construction Provides High Load-Carrying Capacity

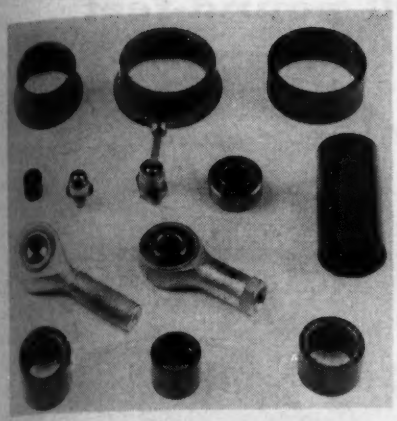
A comparative newcomer to the recently developed group of self lubricating bearings is "Fabroid", a durable bearing of specially reinforced plastic construction, reported to be unmatched for high unit load, long life, low-friction and high temperature applications. Designed by the Micro-Precision Div. of Micromatic Hone Corp., L.A., California, Fabroid is a fabric woven of both fibrous glass and Teflon fibers and backed up by a second fabric of glass cloth impregnated with phenolic. The glass-phenolic system acts as a lattice work or honeycomb, trapping the Teflon to prevent it from cold-flowing.

In Fabroid journal bearing applications a material was required to support the Fabroid bearing element. The material had to be capable of being transfer molded, had to provide a good bond between itself and the Fabroid element and possess other desirable characteristics. Durez 16771 phenolic molding compound, a development of the Durez Plastics Div. of Hooker Chemical Corp., North Tonawanda, N.Y., was chosen because it met these requirements, showed excellent molding qualities, compressive strength resistance to many oils, acids and alkalies. In addition, it has good dimensional stability and operates efficiently at elevated temperatures.

Fabroid's two chief features are its high load-carrying capacity and long life, which are said to result from combining two factors, restraint of Teflon's cold-flow tendency and the inherent strength of its Teflon fibers compared to other forms of Teflon.

In making self-aligning bearings and rod ends, Micro-Precision uses a multi-part metal assembly with Fabroid as the lubricating bearing element. In producing journal bearings, Fabroid cut to size is placed in a transfer molding die and Durez 16771 phenolic molding compound is transfer-molded around the Fabroid liner. A tolerance of 40 millionths is held for sphericity with a finish of 4 microinches, rms.

Use of Fabroid bearings is limited thus far to high unit load, low velocity applications. Until more can be learned, Micro-Precision does not recommend them for high surface speed, low-load applications. Fabroid bearings require no lubrication between bolt and ball bore. Because frictional resistance be-



Self-aligning spherical components, rod ends, and plain journal bearings manufactured by Micro-Precision Div., Microsonic Hone Corp., L. A., Calif., using Fabroid as the bearing element.

tween bolt and ball is higher than that between ball and Fabroid, there is no turning of ball on bolt.

Because it is too porous to support an abrasive and since it remains unaffected by most corrosive materials, Fabroid has proven very successful in tests performed to date.

For more information on Durez 16771 phenolic molding compound:
Write No. 179 in Box on Inquiry Card
For more information on Fabroid bearings:
Write No. 180 in Box on Inquiry Card

SILICON EPITAXIAL TRANSISTORS

Processing Technique Reduces Collector Resistance and Switching Time

Developmental samples of a silicon epitaxial transistor are now available. According to Dr. E. M. Baldwin, V. P. and Gen. Mgr. of the Rheem Semiconductor Corp., Mountain View, Calif., it is the first of a line of epitaxial transistors planned for production at Rheem.

Epitaxial deposition techniques which were described in the 1960 August issue of Electromechanical Design, have been proclaimed as possibly the greatest processing improvement since diffusion techniques were first used for making transistors. The basic process in making epitaxial transistors at Rheem consists of depositing a very thin layer (about one-half mil thick) of high resistivity silicon on a thicker substrate of very low resistivity material. Using this material, transistors are fabricated using the same diffusion

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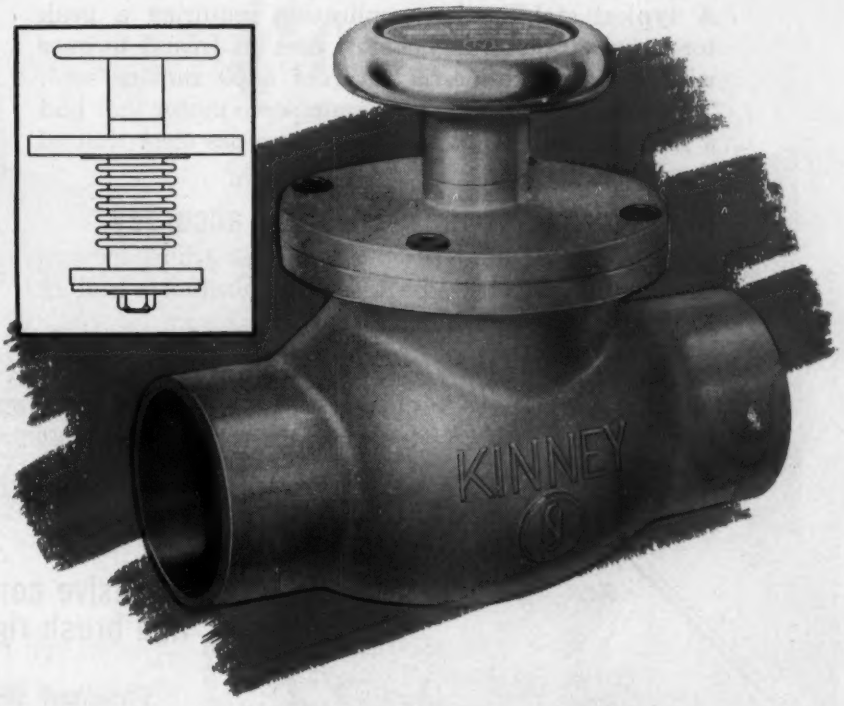
BBSM VACUUM VALVES
say, "STOP" and "GO" and Mean It!



The new Series BBSM KINNEY Vacuum Valves form a reliable force of "Traffic Cops" for your Vacuum systems. In sizes 1", 1½", 2" and 3", these Bronze Bellows Sweat Fitted Valves are especially designed for Vacuum applications having soldered or brazed manifolding. They are of the globe type with non-rising stem, with positive isolation of rotating parts. The brass bellows is sealed to the seat disc and bonnet flange by static "O" rings of Buna N.

Assembly of KINNEY BBSM Valves into the Vacuum system is supremely simple. Removal of stem, cover and bellows assembly as a unit from the body of the Valve is accomplished by unscrewing four cap screws – thus replacement of bellows is no problem. Each KINNEY BBSM Valve is mass spectrometer leak tested to assure vacuum tightness.

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Please send me Bulletins 3421.1A and 3421.3 giving full information and prices on KINNEY BBSM Vacuum Valves.

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Company_____
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CIRCLE NO. 20 ON INQUIRY CARD

For fast, high-resolution servo positioning

Inland d-c torque motors

From 0.1 to 3000 pound-feet

High torque-to-inertia *at the output shaft*

A typical stabilization application requiring a peak torque of 60 ounce-inches now uses an Inland torquer with a torque-to-inertia ratio of 5350 radians/sec.^{2}. This torquer replaces a gear train servo motor that had a ratio at the output shaft less than *one-tenth* that of the Inland torquer.

Direct drive promotes system accuracy

Direct drive without servo motor gear trains reduces friction and eliminates backlash and elasticity, leading to better over-all system accuracy.

COMPACT PANCAKE SHAPE now available in d-c torquers through exclusive Inland design

Exclusive commutator and brush rigging design

Patented features enable Inland to combine the compact pancake configuration with low-power input —high-torque output characteristics of a d-c torquer.

TYPICAL RATINGS FOR 20 OZ.-IN. TORQUERS

	T-1321-D	T-1321-B	T-1321-C
PEAK TORQUE, OZ.-IN.	20	20	20
VOLTS AT PEAK TORQUE, STALLED AT 25°C	31.4	24.8	39.6
AMPS AT PEAK TORQUE	1.82	2.25	1.46
TOTAL FRICTION, OZ.-IN.	0.5	0.5	0.5
ROTOR INERTIA, OZ.-IN. SEC.^{2}	.001	.001	.001
WEIGHT, OUNCES	5	5	5

Inland Power Amplifiers

Inland makes a complete line of power amplifiers for systems duty with Inland torquers whether in airborne, shipboard, or ground service. Specification sheets available on request.

For complete data on these or other d-c pancake torquers up to 3000 pound-foot output, address Dept. EL, Inland Motor Corporation of Virginia, Northampton, Massachusetts.

Factory: Radford, Virginia

INLAND MOTOR CORPORATION OF VIRGINIA

A SUBSIDIARY OF KOLLMORGEN CORPORATION

NORTHAMPTON, MASS.

CIRCLE NO. 21 ON INQUIRY CARD

techniques as for other mesa transistors. Since the active part of the transistor is all within the high resistivity material, this process, in essence, provides a method for handling one-half mil thick silicon slices.

Two major advantages of expitaxial transistors are the virtual elimination of the collector series resistance and a large decrease in storage and turn-off times.

Rheem's RT409 transistor is a 60 volt collector breakdown unit. Typical collector to emitter saturation voltage at 150 ma has been reduced by a factor of 2. Storage time is typically less than 100 millimicroseconds for the same test conditions which yield 400 millimicroseconds in Rheem's 2N697 series. Since the power dissipation is low, the RT409 transistor may be operated at higher current levels.

Rheem plans to improve other transistors in their line using epitaxial film techniques. The company expects that their future units will combine the benefits of high breakdown voltage, low saturation voltage, high current and low storage, which will dramatically demonstrate the advantages of epitaxial transistors.

Developmental samples of the RT409 transistor are available six weeks after receipt of order at $170 each, according to the company. Initial orders are limited to a maximum of ten units.

Frank Breene, Chief Applications Engineer at Rheem, stated, "The combination of epitaxial deposition with diffusion techniques in silicon transistors will enable the replacement of MADT and SADT types. In addition, as soon as these epitaxial units are designed into production equipment, we can see the beginning of obsolescence of the present diffused mesa techniques."

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WORTH BUYING

Zener Diodes

100 page study of zener diodes begins with an introduction to semiconductor theory and reverse breakdown and follows with a detailed and illustrated examination of design considerations and thermal and operating characteristics of the diodes and reference elements. Chapters on applications include audio and rf, AC and DC, computer and instrumentation and circuit protection. Price $2.00.

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SUB-MINIATURE
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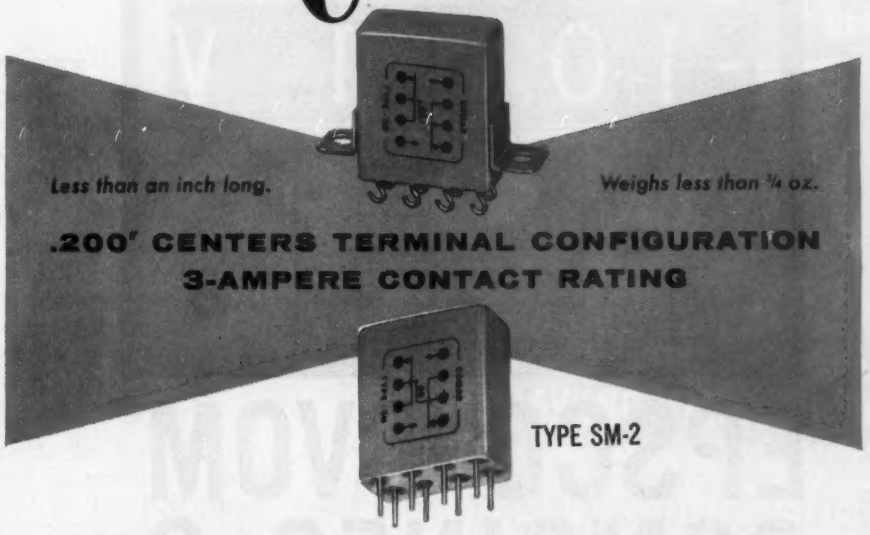

A high precision, efficient sub-miniature relay. Constructed to withstand severe vibration, heavy shock and temperature extremes. For control systems, missiles, computers, aircraft and similar applications requiring miniature size and dependable performance.

Nominal Coil Voltage: 26.5 Volts D.C.
Maximum Pull-In Voltage: 18 Volts D.C.
Maximum Drop-Out Voltage: 14 Volts D.C.
Coil Resistance: Approximately 600 Ohms.
Contact Arrangement: 2 P. D. T.
Contact Rating: 3 Amps. @ 28 V. D. C. Resistive (max.).
Maximum Operate Time (N.O. Contacts): 4 Milliseconds.
Maximum Release Time (N.C. Contacts): 3 Milliseconds.
Maximum Contact Bounce: 1 Millisecond.
Dielectric Strength: 1000 V. RMS, 60 Cycles (Sea Level).
Minimum Insulation Resistance: 1000 Megohms.
Maximum Contact Resist: 0.05 Ohm; 0.10 Ohm (After Life).
Temperature Range: −65° to 125° C.
Operating Shock: 50 "G" for 11 Milliseconds.
Vibration: 20 "G"—5 to 2000 CPS.
Life: 100,000 Operations (Minimum).
Maximum Weight: .60 Oz.
Meets MIL-R-25018 and MIL-R-5757C specifications.

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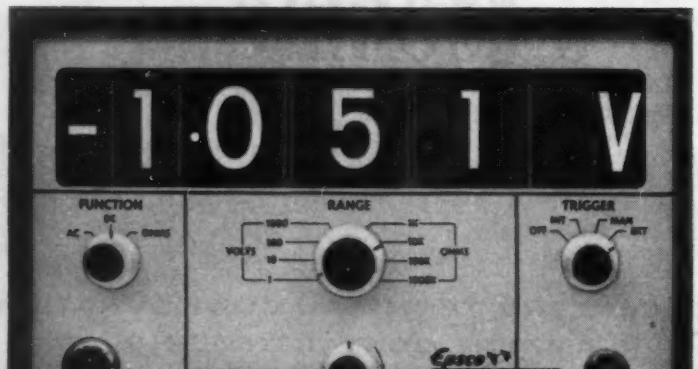
EPSCO DELIVERS ITS SPECIFICATION



EPSCO DVOM® COMBINES 9 FEATURES IN 8¾" x 5¼" x 13¾"

QUICK SPEC CHECK–compare with your needs:

- AC and DC voltages from 0 to 1000 (four ranges)
- Resistance: 1K to 1000K (four ranges)
- Accuracy: DC – 0.1% AC – 0.25% Ohms – 0.25%
- 3 decimal digits plus over-ranging

For complete specifications, call or write today for Bulletin 26002.

HERE ARE THE 9 FEATURES: 1. Measures AC volts, DC volts and ohms. 2. Parallel decimal and 4221 BCD output. 3. 4 milliseconds per conversion. 4. All solid state circuitry. 5. Modular, plug-in construction. 6. In-line, in-plane display. 7. 100 independent measurements per second. 8. Internal and external conversion command. 9. Mount two, side by side, in a RETMA rack.

Epsco INSTRUMENTS

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CIRCLE NO. 23 ON INQUIRY CARD

WORTH FILING

Laminated Plastics

12 page manual contains a quick-reference chart of characteristics for 21 commonly-used laminate grades. Information on how to specify and order laminated plastics includes: thumbnail description of high-pressure laminates; the difference between minimum, maximum property values and average values; where and why laminate property values differ from the specification properties listed for metals and step-by-step instructions on how to use the reference chart.

Source: Taylor Fibre Co., Norristown, Pa.

For your copy: Write No. 418 on Inquiry Card

Terminals

36 page catalog covers terminals, terminal boards and strips, banana jacks and plugs and other parts for industry and the military. Also contained are charts of basic information on typical values of laminates, including general physical and electrical properties of those used in manufacturing terminal boards and special fabricated parts.

Source: National Tel-Tronics Corp. Yonkers, N.Y.

For your copy: Write No. 307 on Inquiry Card

Component Testing

Guide is available to aid the design engineer in choosing the right test and sensing component. Chart contains complete specs on panel lights, switches, fuseholders, test prods and jacks and molding materials. Guide can be tucked into vest pocket or hung on a wall for ready reference.

Source: Alden Products Co., Brockton, Mass.

For your copy: Write No. 308 on Inquiry Card

Connectors

52-page catalog describes a complete line of plug and receptacle connectors with crimp-type snap-lock contacts. A selector chart details many significant characteristics. Technical discussion of plating types with specific applications along with a discussion of installation tooling, its functions, features and characteristics are included. Miniature rectangular, rack and panel, coax and miniature coax, modular, general purpose, printed circuit-edge-type and pin type and other connectors are covered.

Source: Burndy Corp., Norwalk, Conn.

For your copy: Write No. 332 on Inquiry Card

PRODUCTION AIDS

If you want more information on the production aids discussed below write the appropriate number on the reader service card.

ALL-PURPOSE THERMOPLASTIC WELDER **876**

serves in both shop and field with production rates up to 60 inches per min. Designed for welding and tacking thermoplastics such as polyethelene, polypropylene, PVC and plasticized tank linings, the unit plugs into any 115v ac outlet. Kamlar Products Co., Norwood, Mass.

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with a self-contained unit suitable for incoming inspection, on-line inspection and laboratory use. Life testing complies with proposed JEDEC specifications. Offers three advantages over conventional testing: forward and reverse currents adjust independently, handles a wide variety of forward currents, and saves over $200 in operating costs over the course of a 1000 hr. life. Wallson Associates, Inc., New York, N.Y.

SERVO MOUNT CLAMPING SYSTEM **878**

holds all types of servo mount components for experimental and production purposes. Ideally suited for fast changes in production testing, kit contains all necessary hardware. Template supplied for fast hole layout. Angler Industries, Metuchen, N.J.

PRINTED CIRCUIT SOLDERING MACHINE **879**

reduces warpage of printed circuits as only 1½ in. maximum width of solder touches board at one time. Provision for removing excess solder prevents "tear drops" or "tails" from forming on bottom of panel. Dee Electric Co., Chicago, Ill.

C-RING ASSEMBLY PRESS **880**

speeds potentiometer component assembly. Holding pre-stacked rings, it automatically clamps C-rings to high precision centerless-ground potentiometer shafts. The press accepts any size retaining ring, loads easily, and handles other C-Ring assembly applications. Altomac Corp., Canton, Mass.

"HOW OTHERS DO IT" **881**

publication contains ideas submitted by plant engineers and electricians showing how they've used snap-action switches to increase production efficiency. The publication, "Micro Tips," awards free electric clock thermostats for ideas published. Minneapolis Honeywell Reg. Co., Freeport, Ill.

TAPE CONTROLLED MACHINE TOOL **882**

mills, drills, bores, reams, and taps. Said to reduce tooling costs and nonproductive machine time while optimizing machining processes through an automatic tape command. Designed on the building block principle, it machines part sizes up to that containable within a 12 in. cube. Hughes Aircraft Co., Los Angeles, Calif.

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operate at temperatures up to 200C with no deformation under load; they are 80% harder than normal solder alloys at this temperature. Competitive in price, the preforms contain neither boron nor free iron, making them suitable for transistor joints. Melting range: 240 to 268C; forms available: washers, discs, spheres and pellets; tolerances: 0.0001 and 0.0002 depending upon form. Accurate Specialties Co., Hackensack, N.J.

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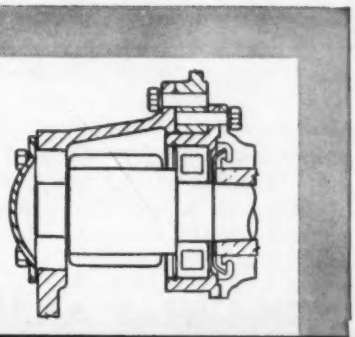
meters and installs all types of screws, bolts, pins, rivets, and studs, from ⅛ to 2¼ in. long No. 14 screw, at rates up to 7000 per hr. Safety check prevents feed of screw to driver unless previous screw seats. Designed for manual and automatic production line use. Clyde Engrg. & Mfg. Corp., Madison Hts., Mich.



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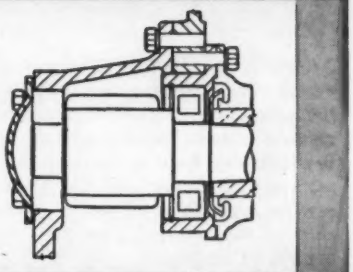

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NON-LINEAR ANALYSIS OF CONTROL LOOP FOR A STABILIZED MOUNT

By Albert Roberts, *Member Planning Staff, General Precision, Inc., Pleasantville, N.Y.*

If some simplifying assumptions are made, a position servo with rate damping can be considered as composed of three independent branches that relate to position, rate and torque elements and their associated components. Each of these branches can limit in any combination or sequence, affecting the response of the system. By graphical means, a "torque picture" can be superimposed on the phase plane to clarify the relationship of the limiting combinations thus allowing prediction and control of responses.

A basic requirement for many airborne high resolution radars or aerial cameras is a stabilized mount which keeps its orientation in space regardless of airframe motions encountered in flight.

One method of providing such a stabilized platform is to slave a balanced two axis (roll and pitch) gimbal system to a vertical reference, and place the sensor such as a camera or antenna on the inner gimbal. Steadiness and control system stability without networks can be achieved by providing space rate damping negatively fed back into the control loop from an inertial sensor such as a rate gyro mounted on the stabilized platform. The control loop is essentially a position servo with rate damping. If some simplyfing assumptions are made concerning structural design and component dynamic response, the loop can be considered as composed of three functional blocks that relate to position, rate and torque elements and their associated components. A block diagram for one axis is shown in Fig 1.

In the ideal case, the platform will remain fixed in space regardless of airframe deviations and $\theta_o = \theta_i$ with no error voltages developed. In the practical case, gimbal friction, unbalance torques and null voltages must be overcome by developing a counter torque. Maximum torque requirement is related to the torque magnitude of the error-causing factors. It is desirable to keep the maximum torque requirement as low as possible from a weight, space and power saving viewpoint but a high torque gradient keeps vertical errors low.

NON-LINEAR CONDITIONS

With the use of high torque gradients and low maximum torques, the range of linear operation can be quite small compared to the overall gimbal range. The angular error off vertical in which linear operation exists may be in the order of minutes of arc. In the practical case, where mechanical stops limit the angular displacement, the total platform range may be only a few degrees off vertical. Thus, torque saturation and non-linear operation will occur if the platform is pushed in excess of a few minutes off vertical by the stops when high amplitude roll or pitch maneuvers occur.

In some photographic work, and with radar antennas, requirements call for a return to null as quickly as possible. Other TV or photographic requirements call for a rate of return to null slow enough so that exposures may be obtained without affecting resolution. The necessity arises to predict and control the response, or trajectory, of the platform when non-linear operation occurs.

In addition to the occurrence of torque saturation, it is also possible from the dynamic conditions, that either or both the rate sensor (K_r) and position sensor (K_θ) signals will limit at levels independent of each other and the value of torque saturation. The interrelationship of the saturating components can give rise to several different types of response or trajectories when the platform is not

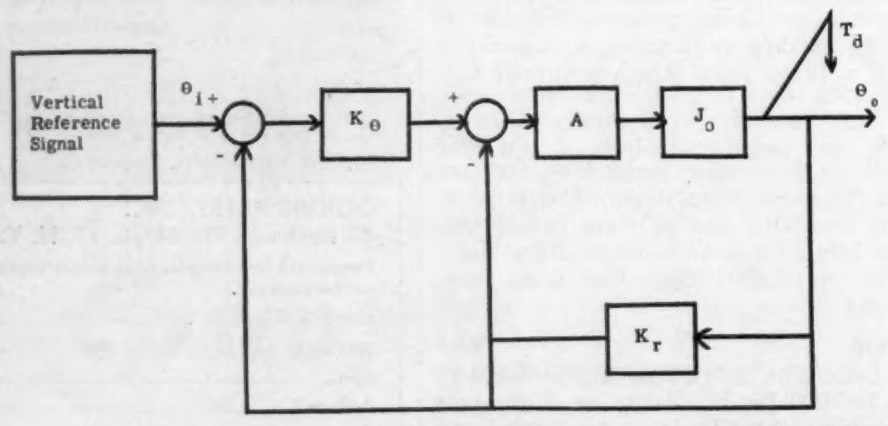

Fig 1 Block diagram for one axis of the gimbal system.

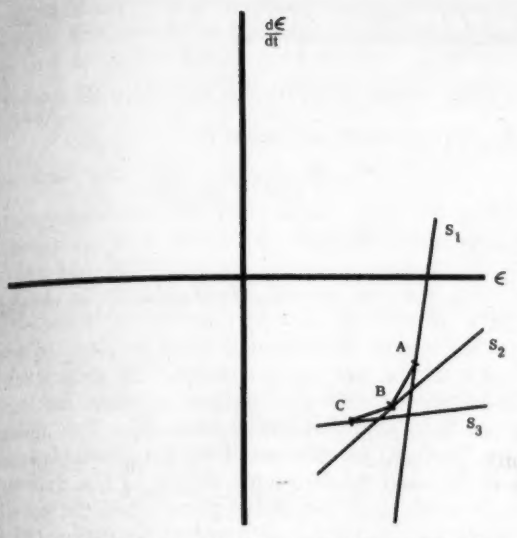

Fig 2 Velocity (dϵ/dt) vs. displacement (ϵ).

in the linear or null region.

Various responses that result can be expressed as a plot of velocity error vs. displacement error as in the usual phase-plane analysis for a second order differential equation. However, another method to obtain these trajectories, described below, more clearly exposes the relationships between the various conditions of saturation or limiting.

METHOD OF ANALYSIS

The trajectories of velocity error vs. displacement error, are obtained with initial conditions of $\theta_1 = 0$ and θ_0 having the initial velocity and displacement values. This is the condition existing when the platform is pushed off its axis by large aircraft rotations.

The procedure, as shown in Fig 2, is to project the curve, so the slope at any point is the same as the calculated value at the point. Assume that at the starting point A, the slope is S_1. In order to project the curve, the slope S_2 must be known in the area of intersection of the slope line with the trajectory. A line is drawn starting at point A to point B with a slope that is the average of S_1 and S_2. This procedure is contined for additional increments, with the trajectory plotted from the knowledge of the slopes at all points in the phase plane, but without prior knowledge of the coordinates of all points on the trajectory. The increments of projection can be as small or large as desired, depending on the accuracy required. A continuous curve is drawn through the plotted increments to give a smooth trajectory.

In the usual graphical construction, lines of constant slope (isoclines) are plotted and the trajectory drawn so that its slope at the intersection with an isocline agrees with slope required by the isocline as described above. Separate sets of isoclines must be drawn for each mode of saturation.

The method enables the rapid calculation of the slope at any point from a knowledge of inertia load, the net applied torque, and the velocity at that point. The net applied torque is previously determined for all sections of the velocity-displacement plane which corresponds to the various modes of limiting. The fundamentals of this method are shown by the following mathematical analysis. Consider the equation of motion:

$$J_o (d^2\theta_o/dt^2) = T_d \text{ when } \theta_i = 0, \theta_o = -\epsilon \qquad (1)$$

$$\therefore \; d^2\epsilon/dt^2 = -T_d/J_o \qquad (2)$$

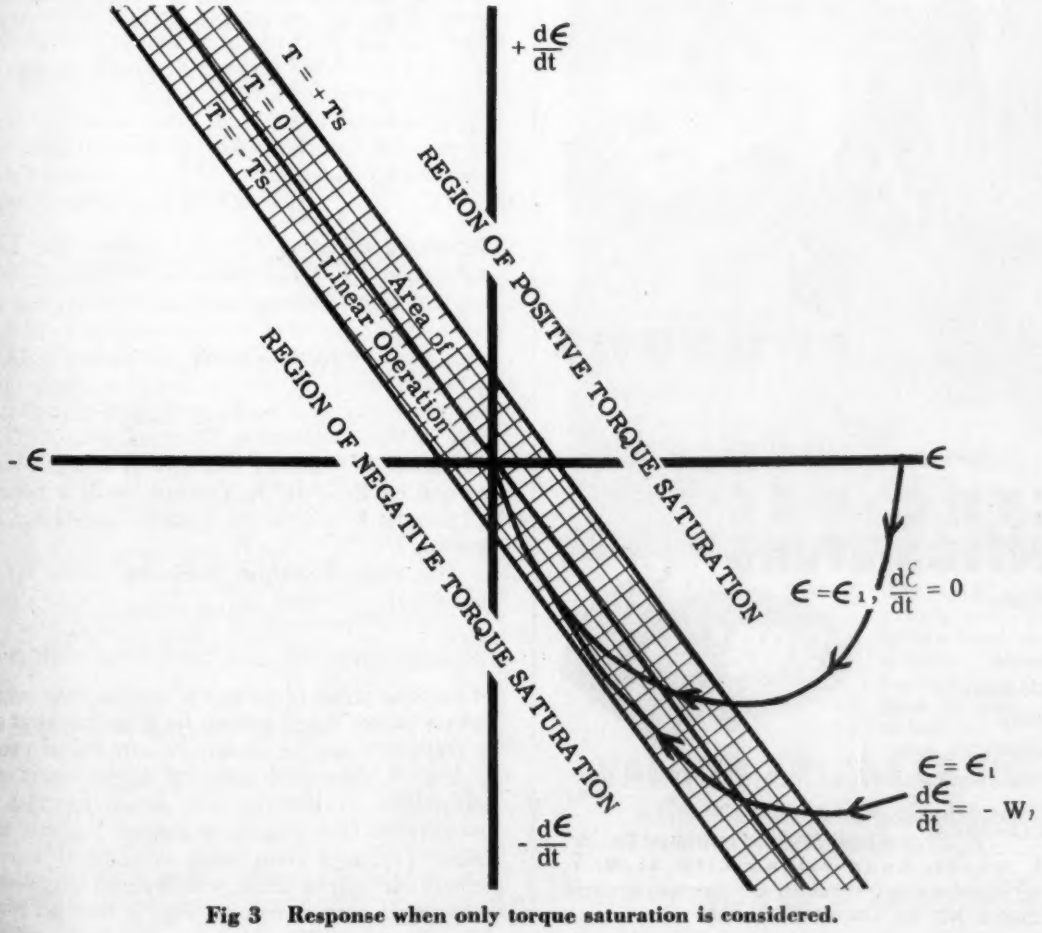

Fig 3 Response when only torque saturation is considered.

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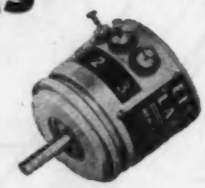

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The slope S at any point on the trajectory on the velocity ($d\varepsilon/dt$) displacement (ε) plane is:

$$S\,(d^2\epsilon/dt^2)/(d\epsilon/dt) \tag{3}$$

and substituting (2) into (3)

$$S = -\,T_d/J_o\,(d\epsilon/dt) \tag{4}$$

Since the inertia is known, S can be obtained from a knowledge of the net applied torque T_d at any velocity. It will be shown that the torque variation for different modes of saturation is easily obtained. This results in a torque "picture" superimposed on the phase plane which can then be used to determine slopes as the trajectory is drawn. In sections of the phase plane when the net torque is constant (as in torque saturation), equation (2) indicates a constant acceleration which is derived from a parabolic trajectory. Therefore, calculations for slope need not be performed for areas of constant torque saturation if the parabolic equation of $d\varepsilon/dt = f(\varepsilon)$ is derived and points plotted to obtain the trajectory.

The torque pictures and their effect on platform trajectories are determined for the following combinations of saturating components:

- Torque saturation only
- Torque saturation in combination with rate limiting
- Torque saturation in combination with position limiting
- Torque saturation in combination with rate and position limiting.

TORQUE SATURATION ONLY

Starting with the condition of torque saturation only: when $\theta_i = 0$, the torque developed is:

$$T_d = [K_\theta \epsilon - K_r\,(d\theta_o/dt)]\,A \tag{5}$$

$$T_d = AK_\theta + AK_r\,(d\epsilon/dt) \tag{6}$$

$$\theta_i = 0,\ \theta_o = -\,\epsilon$$

Rewriting equation (6) and defining the limits of torque saturation by $\pm T_s$, gives the following equation for the area of linear operation:

$$d\epsilon/dt = (-K_\theta/K_r)\,\epsilon + T_d/AK_r \tag{7}$$

$$-\,T_s \lessgtr T_d \lessgtr +\,T_s$$

Equation (7) defines a family of straight lines of constant torque on the ($d\varepsilon/dt$, ε) plane with a slope of $-K_\theta/K_r$. (The ratio K_θ/K_r is the velocity constant K_r of the linear system.)

The area of torque saturation exists for the following condition:

$$-\,T_s \lessgtr T_d \lessgtr +\,T_s \tag{8}$$

Thus, the value of torque is now known over the complete phase plane; the slope can be determined at any point; and a trajectory can be drawn for any initial conditions.

Fig. 3 shows the areas of linear operation and torque saturation. Trajectories are shown for two sets of initial conditions. One condition defines a given initial displacement (ε), and zero initial velocity at $t = 0$. The other condition defines initial velocity and displacement values at $t = 0$. It can be seen in Fig. 3 that no trajectory cross-

the region of negative torque saturation. A single overshoot will occur for trajectories starting along the edges of the linear region when initial displacement is negative for $T_d \geqq +T_s$ and when initial displacement is positive for $T_d \leqq -T_s$.

TORQUE SATURATION WITH RATE LIMITING

In the case where the rate signal limits in addition to torque saturation, a new mode changes the torque picture described above. Torque saturation is assumed to occur at the values selected in the above section, and the value of rate limiting is made equal to $\pm\omega_s$, a constant. The torque saturation picture, with the addition of rate limiting, is shown in Fig. 4.

The area of linear operation exists as defined by equation (7), but with the additional limits on this area imposed by the limiting rate.

$$d\epsilon/dt = -K_v\,\epsilon + T_d/AK_r \qquad (9)$$

$$-T_s \gtrless T_d \gtrless +T_s$$

$$-\omega_s \gtrless d\epsilon/dt \gtrless +\omega_s$$

The area of rate limiting is defined by the following equation.

$$\epsilon = (T_d/AK_\theta) - (\omega_s/K_v) \qquad (10)$$

$$-T_s \gtrless T_d \gtrless +T_s$$

$$-\omega_s \gtrless d\epsilon/dt \gtrless +\omega_s$$

Equation (10) is the expression for a family of straight lines parallel to the $d\epsilon/dt$ axis, and defines the area of rate limiting on the $d\epsilon/dt$, ϵ plane.

Outside of the areas of rate limiting and linear operation, all other areas on the $d\epsilon/dt$, ϵ plane are indicative of torque saturation. Torque saturation will exist whenever the combination of rate and position signals causes the torque signal or device to reach a maximum value. In Fig. 4., lines of constant torque are drawn through the area of rate limiting to connect with the lines of constant torque in the linear area. Thus, the lines formed indicate the variation from positive to negative torque saturation existing in the rate limiting and linear areas.

TORQUE SATURATION WITH POSITION LIMITING

Consider the condition where the position signal limits in addition to torque saturation and rate is unlimited. If the torque saturation value is the same as in previous cases, and a limiting position signal of $\pm\epsilon_s$ (a constant) is assumed, the following analysis defines the torque picture: Equation (7) has new limits to define the area of linear operation:

$$d\epsilon/dt = -K_v + T_d/AK_r \qquad (11)$$

$$-T_s \gtrless T_d \gtrless +T_s$$

$$-\epsilon_s \gtrless \epsilon \gtrless +\epsilon_s$$

When position limiting occurs, the following conditions apply:

$$d\epsilon/dt = K_v\,\epsilon_s + T_d/AK_r \qquad (12)$$

$$-T_s \gtrless T_d \gtrless +T_s$$

$$-\epsilon_s \gtrless \epsilon \gtrless +\epsilon_s$$

This is the equation of a family of straight lines of constant torque parallel to the ϵ axis, and defines the area of

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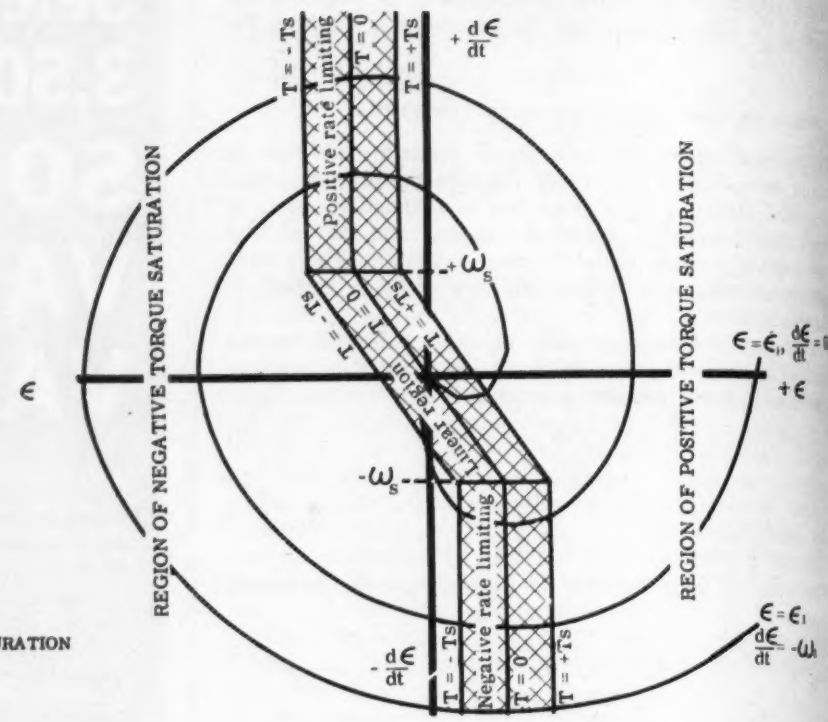

Fig 4 Torque saturation in combination with rate limiting.

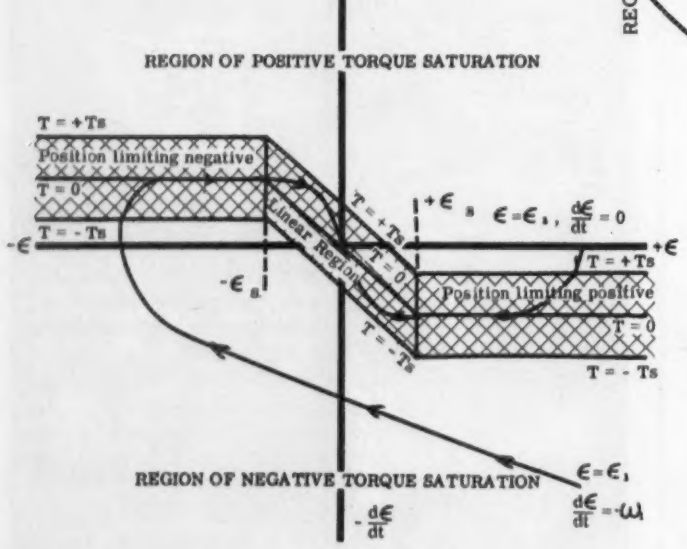

Fig 5 Torque saturation in combination with position limiting.

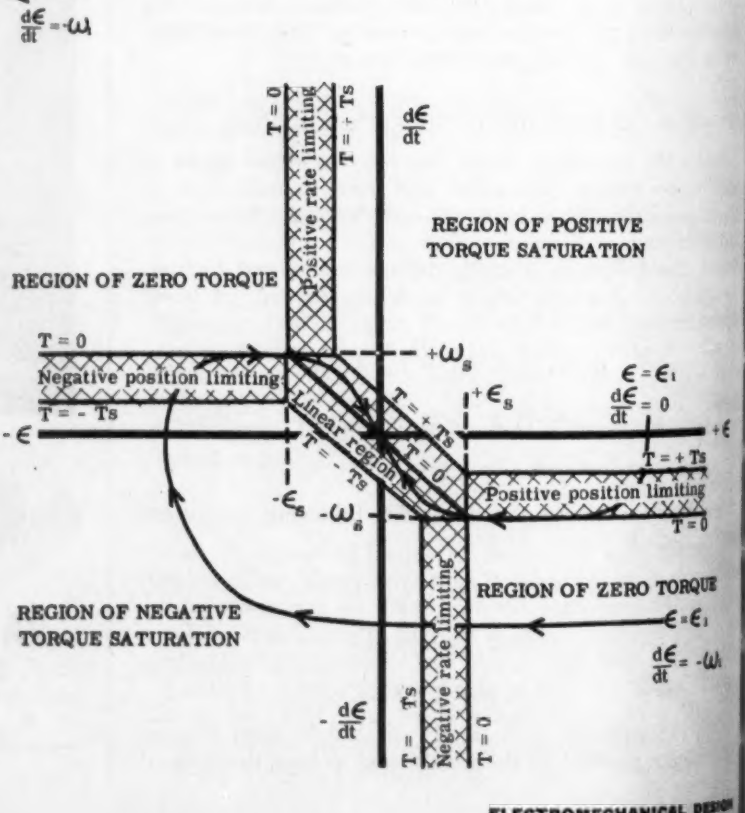

Fig 6 Torque saturation in combination with rate and position limiting.

position limiting.

All other areas on the plane are indicative of torque saturation. For torques developed within values less than saturation, lines of constant torque in the position limiting area connect to like values in the linear area. The return to null is accomplished much more directly than with rate limiting. As indicated in Fig. 5, the trajectories are now parallel to the ϵ axis along T= 0. A return with no overshoots and essentially constant velocity is less than the value fixed by the following defining equation:

$$d\epsilon/dt = -K_v \epsilon_s, T = 0 \qquad (13)$$

This equation relates the velocity and displacement values required to obtain T = 0, and provides the key to eliminate the overshoot effects of rate limiting.

TORQUE SATURATION WITH RATE AND POSITION LIMITING

In the final case, position, rate and torque limiting are considered. The basic requirement is a condition of T = 0 (and S = 0) in an area such that the velocity cannot build up as $\epsilon = 0$ is approached. With T = 0, the torque equation becomes:

$$O = AK_\theta \epsilon + AK_r (d\epsilon/dt) \qquad (14)$$

$$\text{where } \epsilon = (-1/K_v)(d\epsilon/dt)$$

Now if $d\epsilon/dt$ saturates at ω_s, the value at which ϵ must limit is:

$$\epsilon_s = (-1/K_v)\,\omega_s \qquad (15)$$

The above relation defines an area of simultaneous position and rate limiting in which T = 0. The composite effect of selecting this limiting relationship results in a torque picture and trajectories shown in Fig. 6.

Linear operation exists as defined by equation (7) with the following limits:

$$d\epsilon/dt = -K_v \epsilon + T_d/AK_r \qquad (16)$$

$$-T_s \gtrless T_d \gtrless T_s$$

$$-\epsilon_s \gtrless \epsilon \gtrless \epsilon_s$$

$$-\omega_s \gtrless d\epsilon/dt \gtrless \omega_s$$

The following conditions define the area of position limiting:

$$d\epsilon/dt = K_v \epsilon_s + T_d/AK_r \qquad (17)$$

$$O \gtrless T_d \gtrless T_s$$

$$-T_s \gtrless T_d \lessgtr O; \qquad \epsilon \gtrless \epsilon_s; \qquad -\epsilon_s \gtrless \epsilon$$

The area of rate limiting is defined by:

$$\epsilon = (T_d/AK_\theta) - (\omega_s/K_v) \qquad (18)$$

$$O \gtrless T_d \gtrless T_s$$

$$-T_s \gtrless T_d \lessgtr O; \quad d\epsilon/dt \gtrless \omega_s; \quad d\epsilon/dt \gtrless -\omega_s$$

Zero torque area is defined when:

$$\epsilon_s = (-1/K_v)\,\omega_s$$

All other areas on the plane indicate torque saturation.

The trajectories are almost the same as if only position limiting existed, and the overshoot effects of rate limiting are essentially removed. As the value of position limiting is reduced from the maximum value, the torque picture and response becomes more exactly the same as for only position and torque limiting.

These results show that by proper selection of the limits placed upon each functional component in the loop, the response may be predicted and controlled. Practical results were in accordance with the above considerations. ● ● ●

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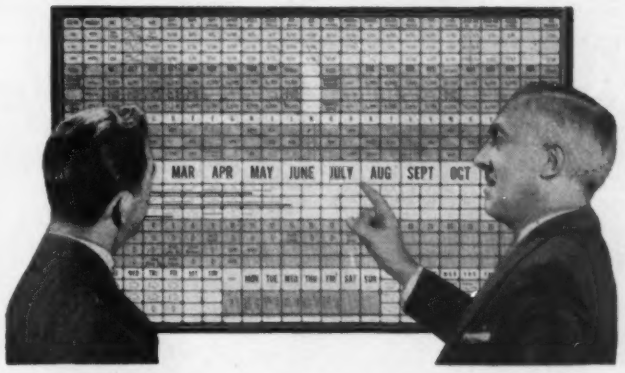

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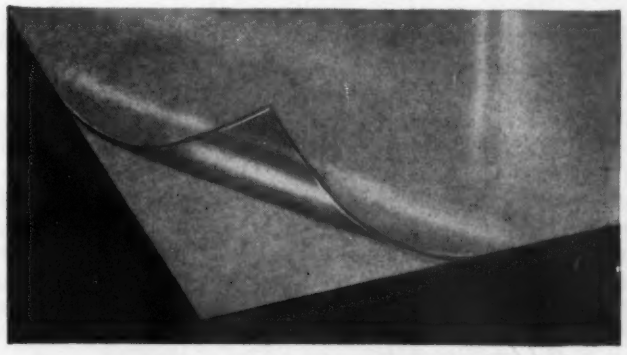

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Recent development of an explosion suppression system for industrial application provides a third protection step which, coupled with existing methods greatly reduces the hazards involved.

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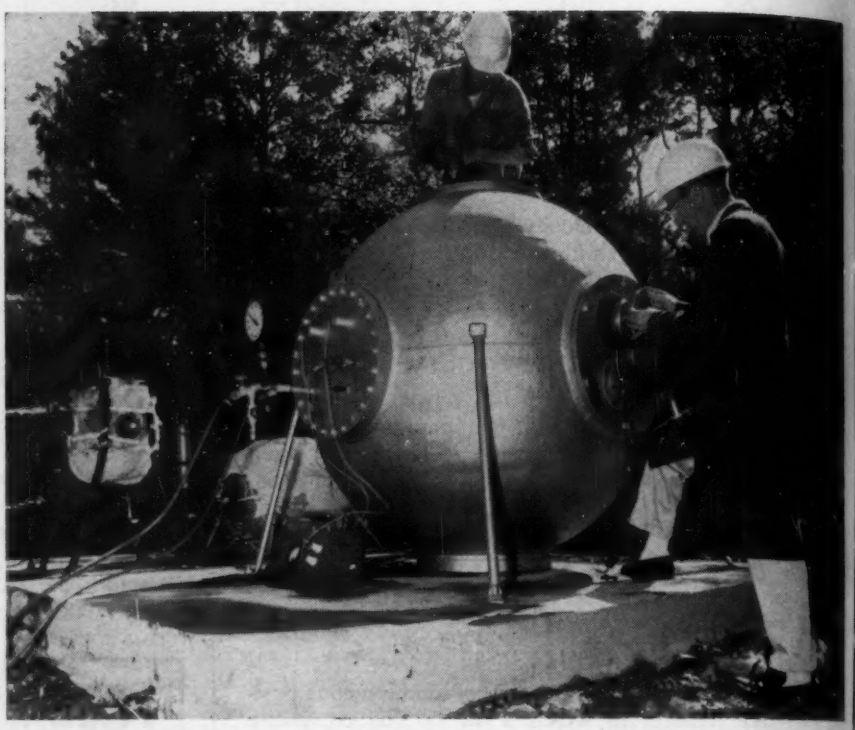


Fig 2 Three of the special explosion chambers which Fenwal engineers use to study the characteristics of various type of explosions. Suppressors are being installed in the largest, 67-cu ft spherical chamber in preparation for another test.

DESIGN BACKGROUND

The Explosion Protection System manufactured by Fenwall Inc., Ashland, Mass., is based upon a British World War II development designed to prevent explosions in aircraft fuel tanks hit by incendiary shells. After the war, Graviner Manufacturing Co. Ltd. successfully adapted it for industrial use. Applications in England are estimated to have prevented losses of several millions of dollars since 1954, and no destructive explosions have occurred in protected equipment. In bringing the system to this country, Fenwal has obtained exclusive U. S. and Canadian manufacturing and sales rights for the system, established continuing technical collaboration with Graviner and independently designed and modified equipment to meet specific U. S. requirements.

The system has been successfully applied to several installations in the United States, and has been proven, either in service or in tests, to be capable of handling most industrial explosion hazards. Its principles can also be adapted to nuclear, missile, aircraft, marine and a variety of other hazardous equipment.

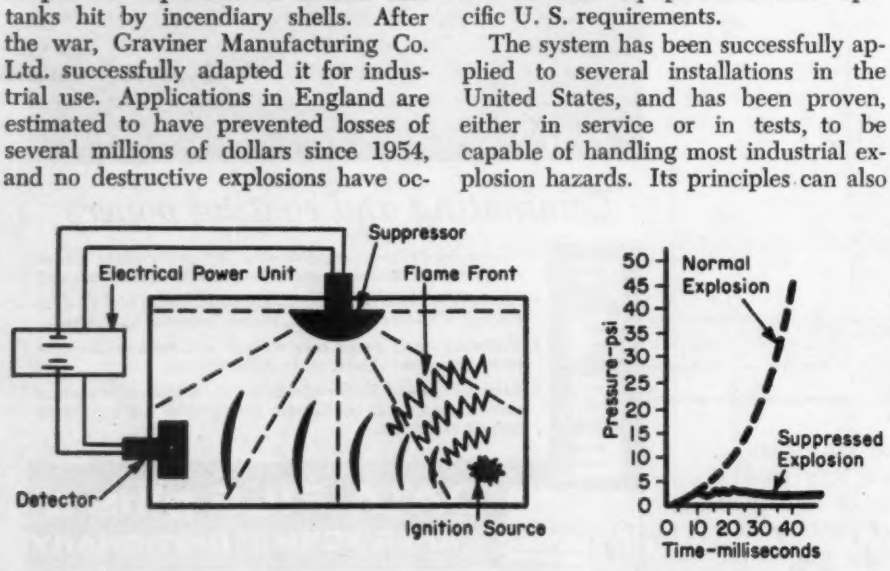


Fig 1 Diagram illustrates the basic suppression system. The detector senses the incipient explosion and the suppressing agent is dispersed explosively. The agent extinguishes the explosion flame by chemical action and cooling, and also inerts the unburned explosive mixture. The graph shows the comparison between a normal explosion curve and a suppressed one. Note the low pressures attained in a suppression.

HOW THE SYSTEM WORKS

System operation is based upon the fact that, although a blast appears instantaneous to the naked eye, there is a finite lapse in time between its ignition and the build-up of destructive pressures. The protection system acts within this period, which is measured in thousandths of a second. (The human eye cannot react to periods shorter than 0.1 second.) In a few milliseconds the system detects the very beginning of the explosion, either by sensing the initial pressure build-up or the first tiny flash of flame, and automatically reacts to snuff it out. The blast is made harmless by a combination of actions, which may include any of the following:

- Suppression—envelopment of the explosion with a suppressant.
- Venting—opening a path to the atmosphere for relief of pressure.
- Advance inerting—introducing a suppressant into areas remote from the source of the explosion to prevent secondary explosions or fires.
- Isolation—blocking the explosion from other areas.
- Automatic plant or equipment shutdowns.

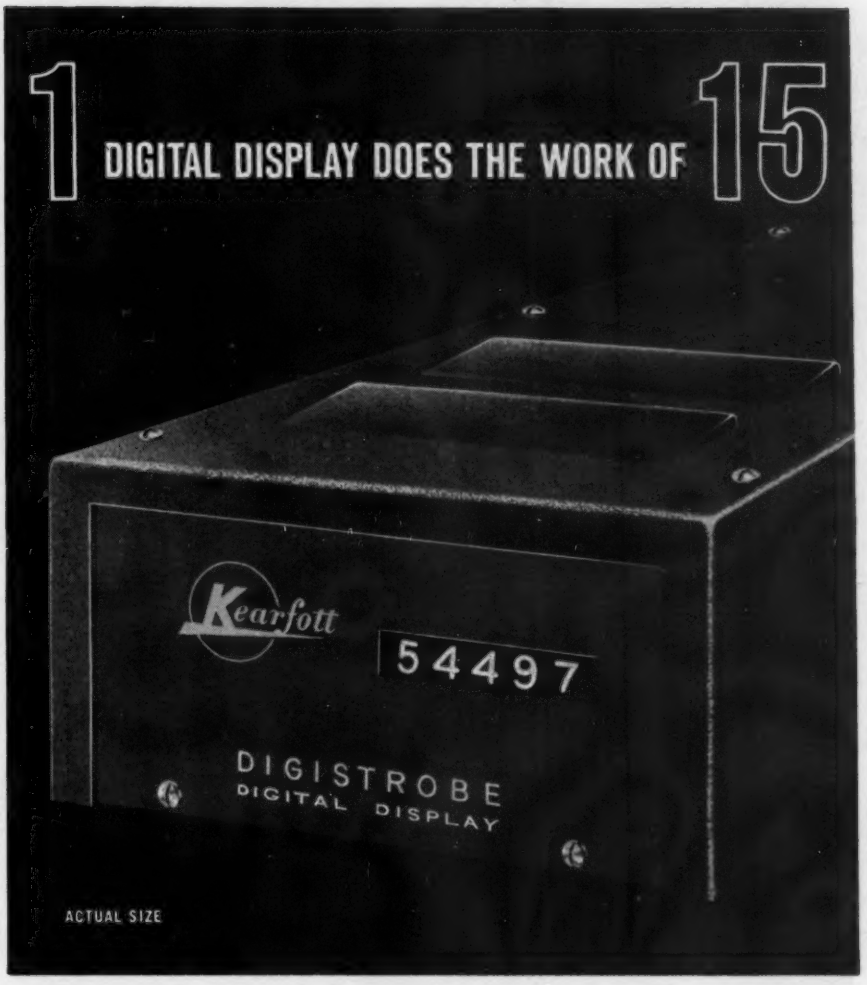
Fig 3 An explosion is about to be triggered from the control house, located some distance from the explosion area. Effects of the explosion are indicated upon the oscilliscope and recorded photographically.

Fig 1 shows the basic suppression system and a graphical comparison of pressure build-up vs. time of a normal blast, and one which has been automatically suppressed.

SYSTEM THOROUGHLY TESTED

Since 1956, Fenwal has been testing the system at a secluded test site near Framingham, Massachusetts. The test center is believed to be the only one of its kind in the United States. Work there has been performed under both Fenwal and private company sponsorship.

Primary research objective has been to investigate the explosion characteristics of various explosive materials. The important conditions of practical explosion problems, such as temperature and pressure and volume are duplicated in special explosion chambers (Figure 2). High-speed electronic instruments (Figure 3) record such information as temperature and pressure build-up with reference to time, of both uninhabited and suppressed blasts.



NEW KEARFOTT DIGISTROBE* DISPLAY

Kearfott's new, highly compact Digistrobe digital display utilizes the stroboscopic principle to produce an exceptionally high-definition readout in the actual size shown here. Through the use of a unique shutter arrangement, a single diode-encoding matrix is shared by all columns (5 in the standard model), resulting in substantial savings in electronic components and circuitry. The fast response time of the Digistrobe (56 milliseconds transition from one five-digit quantity to a totally different one) permits a single unit to sample several different inputs on command through an input selector switch. Up to 15 individual displays of existing types can thus be replaced by a single Kearfott Digistrobe!

Incorporating only two moving parts and exclusively solid-state switching circuitry, the Digistrobe has extremely long life expectancy and requires minimum maintenance and service. Operation is directly from the output register of a computer, counter or allied equipment, eliminating the cost of intervening circuitry. Two years of extensive laboratory tests assure compliance with Kearfott's rigid standards of quality. For complete data and specifications, write for Digistrobe bulletin.

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KEARFOTT DIVISION
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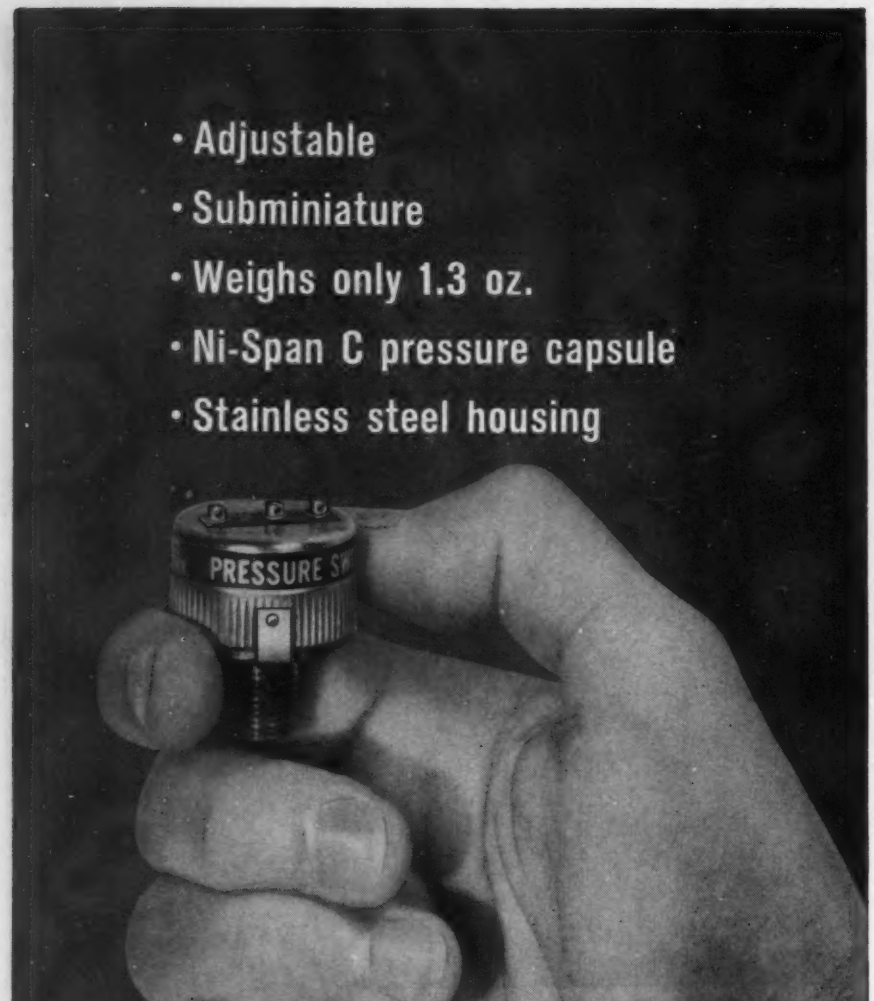

NEW BRISTOL PRESSURE SWITCH

Here's a subminiature pressure switch that incorporates the superb reliability characteristics of larger Bristol pressure switches. Yet, it's both miniature in size and it's adjustable.

It's the Bristol Type C2060 . . . with six models covering ranges from 2-15 psi, absolute, to 20-200 psi gauge.

Easy pressure adjustment. You can change pressure settings easily and simply, without tools. Just turn the top portion of the switch. A strong ball detent holds settings positively even under severe vibration and shock.

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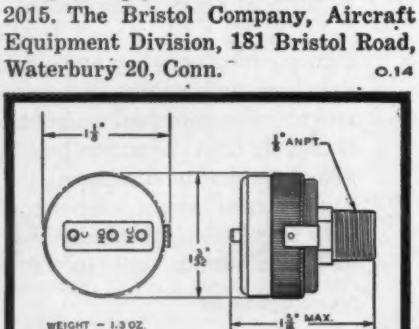
Get complete specifications on the new Bristol adjustable pressure switch today. Simply write for Bulletin AV 2015. The Bristol Company, Aircraft Equipment Division, 181 Bristol Road, Waterbury 20, Conn. O.14



Dimensions

BRISTOL FINE PRECISION INSTRUMENTS FOR OVER SEVENTY YEARS

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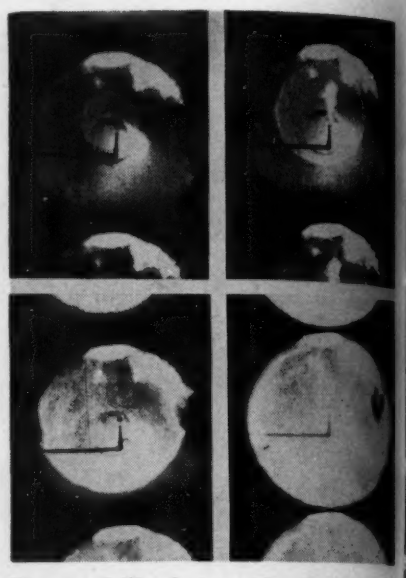

Fig 4 Still photographs from single frames of motion pictures taken at 1,000 frames per second show the development of an unsuppressed blast in a spherical explosion chamber. At top left the dim circle of light just above the center of the chamber shows the fireba'l a few thousandths of a second after ignition. This fireball expands and grows in intensity until after about 50 milliseconds (one-half of one-tenth of a second) it fills the entire chamber (bottom right). "L" shaped bracket supports the explosive material in chamber. Small circle of intense light in center of chamber is sunlight entering through porthole opposite camera.

Sequential still protographs (Figs 4 and 5) taken from high-speed motion picture studies of actual explosions at the test center give graphic evidence of suppression effectiveness. Both are explosions of Stochiometric mixtures (ideal burning conditions) of propane and air ignited by an electric spark. Contrast the build-up of the fireball of the unsuppressed blast (Fig 4) with its suppression in Fig 5.

SYSTEM COMPONENTS

Each explosion protection installation is unique, because it is tailored to meet the specific needs of the protected process or equipment. However, every installation consists of a combination of standard components (Fig 6). Systems can also be designed to protect against fire and explosion hazards by combination with standard extinguishing methods. Such combined systems usually provide considerable savings over separate systems.

Heart of the system is the explosion detector. Either a pressure or radiation device, the detector senses the incipient explosion and, in conjunction with a

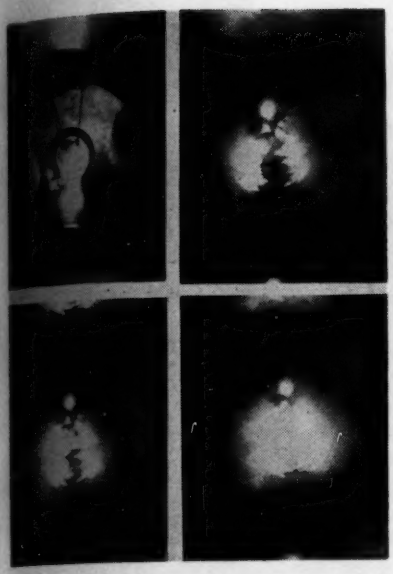

Fig 5 Still photographs from single frame of motion pictures taken at 1,000 frames per second show the suppression of the same type of blast as in Fig 4. A few milliseconds after ignition (top left) the suppressors, located at each side of the chamber, have already begun to discharge suppressant. Succeeding frames show the suppressant mist progressively enveloping the fireball. Leading edges of the two advancing fronts of suppressant mist reflect the intense light of the explosion which is being snuffed out. At lower right the explosion fireball is completely enveloped by suppressant and all but extinguished—in less than 50 milliseconds.

power unit, generates an electrical signal. Pressure detectors are sensitive to either the rate-of-pressure-rise or to a specific static pressure, or to both. A signal occurs when the pressure rise from the incipient blast exceeds either setting, indicating an explosive condition. Radiation detectors are designed to selectively sense certain wave lengths of the spectrum which exist in an explosive flame but to reject others present in natural or artificial light, thus eliminating potential false alarms.

Upon receipt of a signal from a detector, the power unit, which is equipped with stand-by batteries for safeguard against power failure, delivers electrical energy to operate the various explosion protection devices in the system.

Protection devices may consist of suppressors, isolation valves or vents. All are operated by explosive detonators, similar to the precision electric blasting caps used in seismic exploration, for rapid actuation. It should be noted that the vents are not merely rupture discs blown out by the explosion itself but are opened before de-

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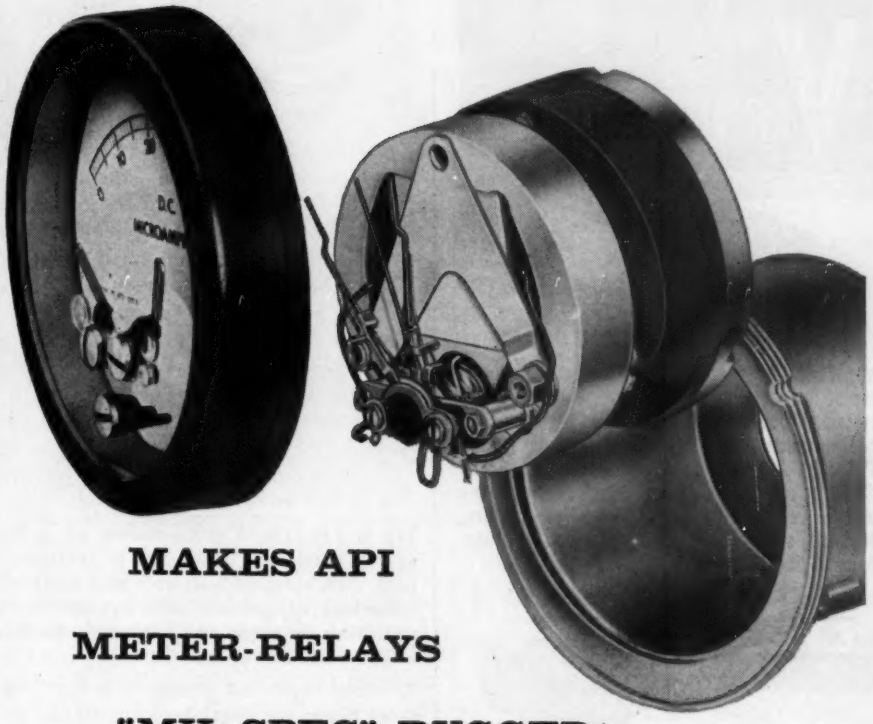
METER MOVEMENT



MAKES API

METER-RELAYS

"MIL-SPEC" RUGGED

Designed to meet applicable provisions of MIL-M-10304, API's new meter-relays are far more rugged than conventional core-magnet types. Reason: the greater magnetic efficiency of the bar-ring movement. It puts more magnetic "horsepower" in the works . . . allows use of more substantial components at a better torque-to-weight ratio. Result: improved resistance to shock, vibration and other environmental factors.

Nicely enough, the bar-ring also provides shielding from external magnetic fields. This means that you can mount the new meter-relays in *any* kind of panel—magnetic or non-magnetic—without worrying about effects on calibration.

As simple to incorporate into a design as a D'Arsonval panel meter (which it is—with control contacts added), the new API meter-relay might well be your best answer to a knotty engineering problem. It can monitor and control almost any electrically measureable variable. It's small and compact. It's reasonably low in cost. And it's reliable—models *without* the benefit of the sturdier bar-ring movement were tested to more than 10,000,000 operations! Have a look at Bulletin 4H, and see if the API meter-relay can't do a job for you.

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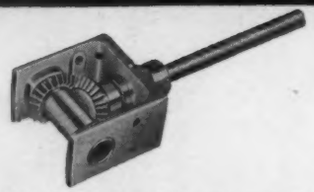
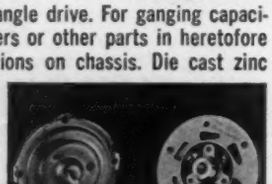
NATIONAL

PRECISION RIGHT ANGLE AND VERNIER DRIVES



Type PRAD: Right angle drive for remote operation of low torque units. Designed for continuous low-speed operation (loads up to 50″ ounces), and intermittent high speed operation (up to 500 RPM) with loads up to 100″ ounces. Less than 1½° backlash; drives and shafts of various lengths; various size output hubs; brass gears; stainless steel shafts, bushings and sleeves; die cast zinc housings.

Type RAD: Right angle drive. For ganging capacitors, potentiometers or other parts in heretofore inaccessible locations on chassis. Die cast zinc housing gears.



Type AN: Time-tested vernier mechanism. Designed for use with any 3/16″ National knobs and others. Drive ratio: 5 to 1; drive shafts: 3/16″, 1/4″ or to specifications; fully insulated output shaft coupling; output hub fits ¼″ shaft; readily adaptable to many types of drives.

Type AVD: Vernier mechanism. Similar to type AN (above) except that output-shaft is non-insulated. Dimensions: over-all diameter 2-9/16″, length 1-15/32″.

Write for new National Company components catalog! National Company, manufacturers of an extensive components line, invite inquiries for these and other electromechanical parts. For special components or a design or development problem, write:

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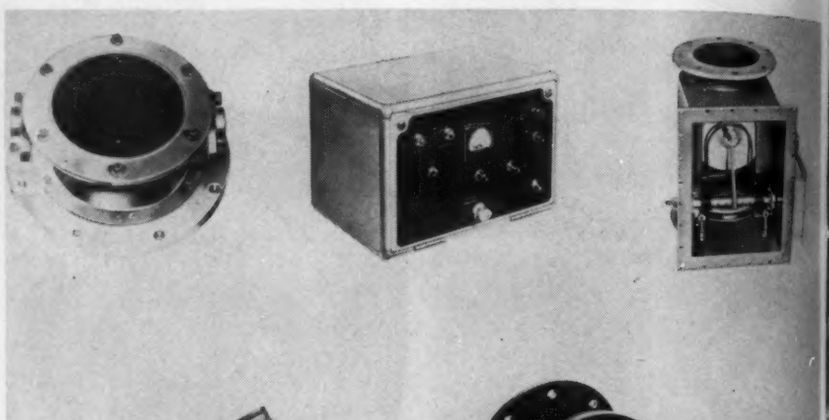

Fig 6 Standard components of a Fenwal Explosion Protection System. Shown at top from left to right: a pressure sensitive explosion detector, special power unit with standby batteries and high-speed isolation valve. Shown at bottom: hemispherical suppressor and explosively actuated vent. Not shown: surveillance or radiation detector and high-rate discharge bottle.

structive explosion pressures occur. The time lapse between ignition of an incipient explosion and the operation of the various explosion protection devices is just a few thousandths of a second.

Suppressors may be easily ruptured hemispherical containers or high-rate discharge bottles. Both contain liquid suppressants. When activated, they dispense the liquid in fine particles moving at speeds up to 600 ft per second. The incipient explosion is cooled by heat of evaporation of the enveloping suppressant mist inhibiting further combustion. The most common suppressants used are water and bromochloromethane. As an example of the quantities of suppressants required, only 5 cc of water or 2 cc of bromochloromethane can suppress an incipient explosion in a one gallon volume.

Essentially the vents are special glass windows which are fractured by an explosive detonator mounted against their outer face. Operation of the detonator fractures the glass, but the elevated pressure of the incipient explosion within insures that fragments will fly outwards, away from the protected space and process. There are two types of swiftly acting isolation valves, butterfly and flap. They are held open, against heavy spring pressure, by a hollow metal link. Operation of an explosive detonator within the link breaks it, allowing spring to slam valve closed and hold it there.

A combination of protection devices is desirable to protect most processes.

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Digital Recording & Control

Transistorized, plug in automatic digital recording and control system with a capacity of 100,000 channels was specifically designed for monitoring and controlling up to ten analog computers of 10,000 inputs each but it can also be used independently wherever data logging, reduction and control are required, such as in process operations. When used in an analog computing facility, the system speeds up or eliminates problem set-up and check-out tasks. Without human intervention, and via punched tape, it can select a computer, place it into any one of its operating modes, set the computing elements such as potentiometers with an accuracy of ±0.01%, read back the voltage variables to check settings of computing elements and then initiate problem solution. The automatic digital system can also verify the selection circuitry involved in performing its function and/or compare any selected voltage with a digital reference value to within an adjustable tolerance as small as 0.01 volt. Computer Systems, Inc., Monmouth Junction, N.J.

Write No. 618 in Box on Inquiry Card

CONTRACTS

Electron beam welding of electrical connections for micro-assemblies will be studied at Hamilton Standard's Electronics department, Windsor Locks, Conn., under a contract from the Signal Corps. The contract covers the development of welding techniques for the interconnection of micro-assembly wafers or substrates, each containing tiny electronic circuits. A micro-assembly is formed by stacking the substrates, which vary in thickness from 0.010 to 0.30 inches thick, one over the other and interconnecting them with vertical wires. In normal manufacturing, solder is used to make the multiple interconnections between the wafers. However, as the parts density increases, smaller connections are needed on the edges than are possible with conventional soldering methods. The electron beam study will explore methods of welding the interconnections at densities of 1,600 per square inch. To illustrate the minuteness of the work, Dept. Mgr. Walter R. Bush noted that a period on a typewriter is 100 times larger than one of the welds that will be made. The Hamilton-Zeiss electron beam welding machine can be focused to a spot size less than 0.010 in diameter and achieve dept to width ratios in weldments as great as 20.1.

For research and experimentation in electronic scanning storage techniques, the Applied Research Lab. of Sylvania Electric, Waltham, Mass. has been awarded a $333,000 Air Force contract. Dr. Leonard S. Sheingold, Director of the Applied Research Lab. said the program is expected to make significant contributions in the intelligence and electronic data processing fields. One technique currently under study should lead to devices able to read or write information 16 times faster than present methods and able to store 40 times as much information as now being stored under conventional methods, he stated. Basic concepts of electronic scanning storage techniques are being studied, as well as development of a digital storage technique, using electronic scanning, recording and data retrieval.

Research in ferromagnetics with applications to new storage devices will be continued at Laboratory for Electronics, Inc., Boston, Mass. under a contract from the Office of Naval Research. The Company has been investigating the area of solid state physics during the past two years concurrent with other company-sponsored research in the field of thin magnetic films. Work involves application of thin magnetic films in high density storage devices and logical elements using the properties of domains and controlled domain wall motion in films. Present studies are aimed at demonstrating the feasibility of microminiature storage techniques leading to devices that will allow information storage densities in the order of one-million bits of information per cubic inch.

Zero-gravity temperature transducers will be supplied to the NASA by Nacimco Products, Inc., San Diego, Calif. The cryogenic transducers are resistance thermometers utilizing deposited platinum film as the sensing elements. Use of film offers the physical characteristics of small size and extreme ruggedness, and the operational stability, accuracy and speed of response needed to meet the rigid requirements of the most advanced aircraft and missile programs.

Briefly:

Optical and electonic simulators and computing equipment: $3,500,000 to Aircraft Armaments, Inc., Cockeysville, Md. from U.S.N. for anti-submarine warfare training center.

Satellite tracking radars: $600,000 to Fairchild Astrionics Division of Fairchild Eng. & Airplane Corp., Wyandanch, N. Y. from the Navy's Bureau of Weapons.

Precision potentiometers: $100,000 to George Rattray and Co., Inc., Hicksville, N. Y., from the U.S.N.

Compass systems: $500,000 to Sperry Phoenix Co., Phoenix, Ariz. from Lockheed Aircraft Corp.

Field communications equipment: $850,000 to Packard Bell Electronics, L. A., Calif. from the Signal Corps.

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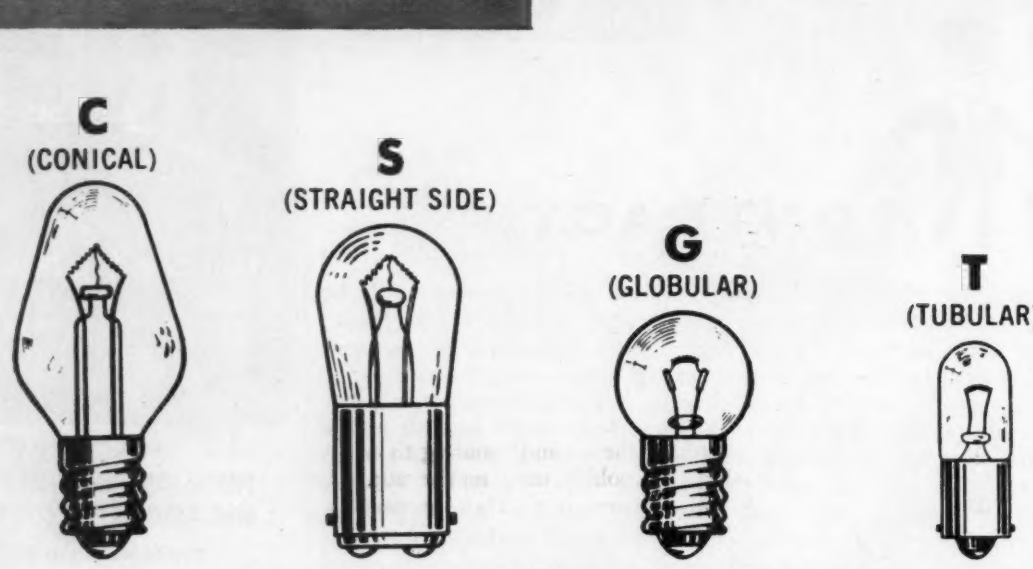


Fig 1 Four common bulb shapes and their designations

SELECTION OF PILOT LIGHTS BY LAMP TYPE

Recently Dialight Corporation of Brooklyn, New York published a 256 page Handbook of Pilot lights which is truly a comprehensive manual designed to tell engineers "how to select the proper pilot light to accomodate the required lamp." This article taken from the Handbook abstracts the basic ideas around which the book is organized and which greatly simplify the selection problem. To obtain copies of the Handbook, interested readers are invited to write for an application form to the Dialight Corporation, 60 Stewart Avenue, Brooklyn 37, N.Y.

Every pilot light is designed to employ one and only one type of lamp (bulb). Some pilot light assemblies may contain two or three lamps; they may have special features; but always the design accomodates a particular lamp type. The lamp will be available in a variety of voltage ratings, but it has a specific bulb size and base configuration. Selection of the lamp is therefore a prerequisite to choice of a pilot light. Given the proper lamp for an application, choice of a pilot light from the tremendous variety available is a relatively simple matter.

CIRCUIT VOLTAGE

The pilot-light lamp must, of course, operate on the voltage available. If a low voltage source from a step-down transformer or battery is at hand it should always be preferred over line voltage. Lower voltage lamps are much stronger, are available in greater range of choice as to size, voltage and current ratings and require less circuit insulation.

For line voltage sources in the 110 to 250 volt range, a choice must be made between incandescent and neon glow lamps. Table I lists the comparative advantages and disadvantages of these two lamp types.

INTERCHANGEABILITY

The lamp industry has standardized lamp designs to the extent that units of any one manufacturer are interchangeable with units of any other. Four types of bulb shapes and seven types of bases used generally are illustrated in Figures 1 and 2.

This standardization has also greatly simplified the problem of classifying and designating lamps. The various classes are generally identified first as incandescent or neon glow, then by bulb shape and diameter and finally by type of base. The bulb shape is indicated by the first letter of its desciptor and the diameter is given in units of ⅛ inches. Thus a G-6 bulb is globular shaped with a 6/8 inch diameter.

Standard designations of individual lamps within these classifications are as follows:

- *Large incandescent lamps* have a code description made up of watts, bulb shape, bulb size, and voltage, in that order.
- *Miniature incandescent lamps* are designated by numbers filed with the American Standards Association.
- *Neon glow lamps* have numbers preceded by NE, assigned by General Electric and generally adopted.

Tables II, III, and IV list the lamps most used in pilot lights.

Fig 2 Lamp bases

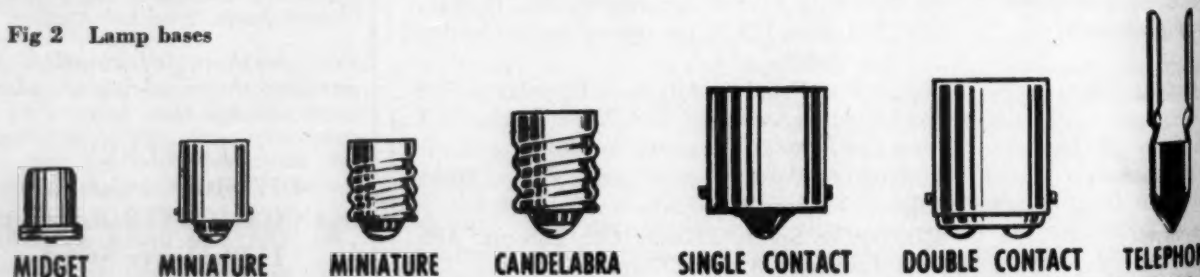


TABLE I
Comparative Advantage and Disadvantages of Incandescent and Neon Glow Lamps

INCANDESCENT

High Light Output
High Wattage, High Temperature
Any Lens Color
Life Short at Overvoltage
Hot Filament Strength Low
For Assemblies Requiring No Less Than 1" Mounting Clearance Hole

NEON GLOW

Less Brightness, but Effective
Low Wattage, Very Cool
Red And Yellow Color Only
Unaffected By Voltage Variation
Extremely Rugged
Assembly For 9/16" or 11/16" Mounting

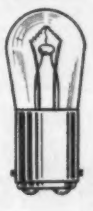
TABLE II
Large Incandescent Lamp Listing

Each illustration represents a group of lamps, alike except for electrical and life ratings.

S-6 Bulb CANDELABRA SCREW Base

← DESIGNATION	RATINGS WATTS	VOLTS	HOURS	DESIGNATION →
6S6—6V	6	6	1500	6S6DC—6V
6S6—12V	6	12	1500	6S6DC—12V
6S6—24V	6	24	1500	6S6DC—24V
6S6—30V	6	30	1500	6S6DC—30V
6S6—48V	6	48	1500	6S6DC—48V
6S6—75V	6	75	1500	6S6DC—75V
6S6—125V	6	125	1500	6S6DC—125V
6S6—135V	6	135	1500	6S6DC—135V
6S6—145V	6	145	1500	6S6DC—145V
10S6—230V	10	230	1500	10S6DC—230V
10S6—250V	10	250	1500	10S6DC—250V

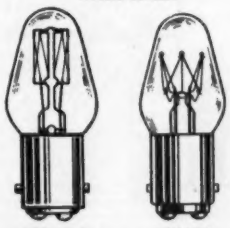
S-6 Bulb BAYONET BASE Double Contact



C-7 Bulb BAYONET BASE Double Contact

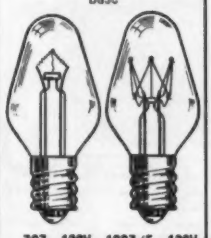
10C7/DC — 10 watts, 120 volts, 6000 hours

C-7 Bulb BAYONET BASE Double Contact



10C7/1DC — 10 watts, 120 volts, 6000 hours
10C7/5DC — 10 watts, 120 volts, 6000 hours

C-7 Bulb CANDELABRA SCREW Base



7C7—120V — 7 watts, 120 volts, 1500 hours
10C7/5—120V — 10 watts, 120 volts, 6000 hours

T-4½ Bulb CANDELABRA SCREW Base

6T 4½/1 — 6 watts, 125 volts, 1500 hours

S-6 Bulb INTERMEDIATE SCREW Base

6S6/7 — 125 volts
10S6/13 — 230 V.; 250 V.

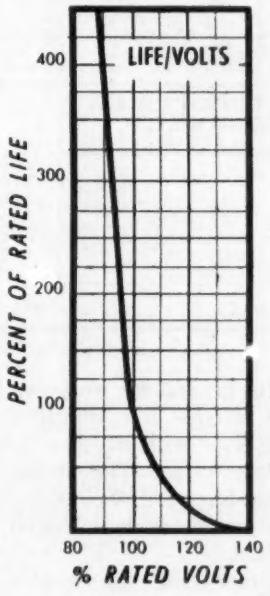


Fig 3

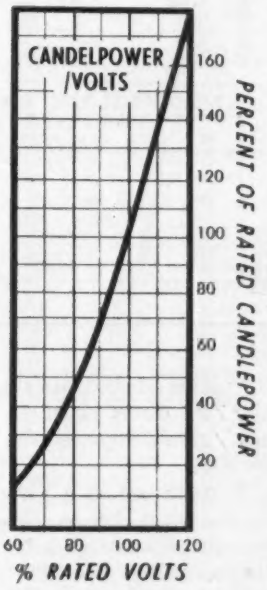


Fig 4

INCANDESCENT LAMP CHARACTERISTICS

Small incandescent lamps for 120 volts and 250 volts must employ the thinnest possible filaments. Tungsten wire of the smallest practicable size is heated to incandescence by currents of 40 to 50 milliamperes. It follows that power rating for such lamps are low—10 watts for 250 volts and 6 watts for 120 volts. The heat produced requires enclosing bulbs of ¾" diameter. Smaller bulbs would be heated to excessive temperatures.

Filaments for lower voltage incandescent lamps are simple and short and of lower power. As a result the bulbs may be much smaller; holding current to minimum values is not necessary; filaments are thicker and much stronger.

Undervoltage Operation. Operation of lamps in pilot lights rarely requires the highest efficiency and candlepower of which the lamps are capable. For reliability and long life voltage ratings should be 10 to 20% higher than the voltage actually to be applied. Exceptions to this rule are when the duty cycle is such that the lamps will be seldom lighted and for short intervals, or when very bright indication is necessary, or for effective use of blue lenses since little blue light is given off by low temperature filaments.

Resistance of the filament to shock and vibration is substantially improved by the lower temperature that goes with undervoltage operation. Figure 3 shows how rapidly lamps fail when subjected to over-voltage. Note that the light produced does not fall too rapidly as voltage is reduced. Figure 4 shows that undervoltage operation is quite practible in pilot lights. Note that the light produced does not fall off too rapidly as voltage is reduced.

Lamp Strength. Lamp filaments are springy and strong when not heated but become nearly plastic and are easily distorted when burning. High voltage filaments are provided with many supports to prevent filament movement. The thicker and stronger filaments of low voltage lamps are preferred when shock or vibration is a problem. Even 12 volt types are inferior in strength to 6 volt types.

NEON GLOW LAMP CHARACTERISTICS

Neon glow lamps are completely unlike incandescent lamps. They produce light without heat by a gaseous electrical discharge as the gas is ionized and deionized. The process also procharacteristic of the neon gas. With neon, the colors are red and yellow only; no green or blue light is given off at all.

A minimum voltage is needed to ionize neon gases. Neon lamps are, therefore, limited to use on line voltages.

TABLE III
Miniature Incandescent Lamp Listing

Each illustration represents a group of lamps, alike except for electrical and life ratings.

T-3¼ Bulb, MINIATURE BAYONET Base

NO.	Manufacturer's Rating VOLTS	AMPS	HOURS	VOLTS for 6000 hours
49	2.0	.06	1000	1.7
45	3.2	.35	3000	2.9
47	6.3	.15	3000	6.0
1847	6.3	.15	Long	6.3
44	6.3	.25	3000	6.0
1891	14	.24	500	12.0
1488	14	.15	200	10.5
1813	14.4	.10	3000	12.5
1815	14	.20	3000	13.3
1826	18	.15	250	14.0
1819	28	.04	1000	24.0
1829	28	.07	1000	24.0
1820	28	.10	1000	24.0
313	28	.17	500	21.7
1828	37.5	.05	Long	37.5
1835	55	.05	Long	55.0

G-3½Bulb—MINIATURE BAYONET Base—G-4½ Bulb

NO.	Manufacturer's Rating VOLTS	AMPS	HOURS	VOLTS for 6000 hours
51	7.5	.21	1000	6.6
53	14.4	.12	1000	13.5
1445	18	.15	250	13.5
*356	28	.17	500	23.0

*for intermittent service only

55	7	.40	500	5.8
57	14	.24	500	11.5

T-3¼ Bulb, MINIATURE SCREW Base

NO.	Manufacturer's Rating VOLTS	AMPS	HOURS	VOLTS for 6000 hours
48	2.0	.06	1000	1.7
42	3.2	.35	3000	3.0
40	6.3	.15	3000	6.0
46	6.3	.25	3000	6.0
1481	14	.15	200	10.5
1487	14	.20	3000	13.3
1827	18	.15	250	14.5
1821	28	.17	1000	24.2
1832	37.5	.05	*(L)	37.5

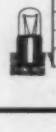
G-6 Bulb, DOUBLE CONTACT BAYONET Base

NO.	Manufacturer's Rating VOLTS	AMPS	HOURS	VOLTS for 6000 hours
64	7.0	.60	1000	6.1
82	6.5	1.0	500	5.4
68	13.5	.59	*(L)	13.5
90	13.0	.71	*(L)	13.0
72	22	.18	200	17.0
1252	28	.23	1000	24.5
304	28	.30	500	23.2
1224	32	.16	200	24.6

G-6 Bulb, CANDELABRA SCREW Base

NO.	Manufacturer's Rating VOLTS	AMPS	HOURS	VOLTS for 6000 hours
63K	7.0	.60	1000	6.1
81K	6.5	1.0	500	5.4
1471	12	.26	250	10.3
67K	13.5	.59	*(L)	13.5
89K	13	.53	750	11.0
71K	22	.18	200	17.0
530	24	.17	250	18.8
1224K	32	.16	250	24.6

T-1¾ Bulb, MIDGET FLANGE Base



NO.	Manufacturer's Rating VOLTS	AMPS	HOURS
331	1.3	.06	500
343	2.5	.40	30
338	2.7	.06	500
328	6.0	.20	500
345	6.0	.04	1000
330	14.0	.08	750
327	28.0	.04	1000

T-2 Bulb, TELEPHONE SLIDE Base

NO.	Manufacturer's Rating VOLTS	Min. (AMPS)	Max.	LIFE
6A	6	0.12	0.16	
12C	12	0.17		Indefinite long life—over 6000 hours
24A	24	0.025	0.035	
24E	24	0.032	0.038	
48B	48	0.09	0.0110	
48C	48	0.032	0.038	
55C	55	0.045	0.055	

*(L)—Indefinite long life, over 6000 hours

Applied voltage should always exceed 105 volts if direct current. "High Brightness" glow lamps require at least 160 volts d-c.

Light is produced as a glow on the negative electrode, hence these lamps are known as negative glow or cathode glow lamps. When operated on a-c, both electrodes glow alternately but at such a high frequency that they both seem to be lighted continuously.

Voltage and Performance. The neon glow lamp has most unusual voltage characteristics. Although minimum voltage is needed just to get it lighted this voltage is enough to make it "run away", that is to pass excessive current, unless some resistance is included in the circuit. The resistance may be in the lamp assembly, inside the base, or in the pilot light assembly. Those glow lamps which have screw bases have the necessary resistor for the circuit voltage for which they are rated. Lamps with bayonet bases have no voltage rating. The circuit voltage is determined by the user and the necessary resistor is included in the pilot light.

In either case the resistor is the dominant factor in determining the lamp current. The life of the lamp is approximately inversely proportional to the cube of the lamp current. Resistor value is selected to give desired balance between brightness and burning life. Normal variations in applied voltage produce only directly proportional changes in lamp current and have minor influence on life performance.

"High Brightness". Some glow lamp types have been modified by the use of a new gas mixture and are called the "high brightness" types. These lamps may be operated at about 3 times the usual level of current with the same hours of life. Their efficiency is also higher so that about 8 times as much light is emitted.

"High brightness" lamps require slightly higher starting voltages and show a more rapid rise with burning. On some circuits they will finally fail to light before they have depreciated in light output to the point of replacement.

Built-In Resistors. Inclusion of built-in resistance in the pilot light assembly has revolutionized the use of glow lamps in pilot lights by eliminating the need for many ratings. The pilot light is simply designed for the special conditions of service with the proper resistor and with a socket for one of the bayonet base neon lamps.

The resistor may be of high ohmic value for 250 volts or low for 95 volts. It may be of high value for very long lamp life or low for brightest light where used in intermittent or infrequent service. A very few sizes of lamps can cover all requirements.

Life of neon glow lamps is long, very long at low loading. It is reduced in about inverse proportion to the cube of the current. Don't look for very bright light from neon glow lamps, but expect extreme ruggedness and dependability.

Neon glow lamps are insensitive to most of the external conditions about them. They are little affected by rather extreme variations in applied voltage. Temperature has little effect from very low extremes to 165 F. "On" and "Off" operation has no effect at all.

The resistor can, of course, be omitted entirely in those applications where the lamp serves a purpose as a circuit component as well as being a light source—providing that current is limited to proper value by the circuit impedance.

The following are some of the special circuit functions glow lamps may perform: voltage regulators, oscillators, limitors, couplers, flashers, pulse indicators, memories.

PILOT LIGHT SELECTION

After choice of a proper lamp bulb, selection of a pilot light is confined to choice from various body types adaptable to the lamp. Modular design further simplifies selection. Where modular elements are used, a wide range of choice within each body type is available in every detail: Lens shape,

CIRCLE NO. 36 ON INQUIRY CARD

TABLE IV
Neon Glow Lamp Listings

T-3¼ Bulb, 1/3 Watt
Miniature Bayonet Base
Types NE-51 and NE-51H
(High Brightness)

These lamp types are extremely versatile general-purpose indicators, useful wherever truly miniature lamps are needed for voltages in ranges 105 to 125, and 210 to 250. The new high brightness lamps may be operated at about three times the level of current that may be applied to standard lamps and they will produce eight times as much light.

Recommended Resistance Values (Ohms)
For NE-51

Applied Volts	105-125	210-250
Best Light	56,000	180,000
Medium Life	100,000	270,000
Long Life	220,000	680,000

for NE51-H

Applied Volts	105-125	210-250
Best Light	18,000	56,000
Medium Light	33,000	120,000
Long Life	82,000	220,000

T-4¼ Bulb, ¼ Watt
Double Contact Bayonet Base
Types NE-48, NE-16, NE-17

Bayonet base lamps require a current-limiting resistor.

Recommended Resistance Values (Ohms)

Applied Volts	105-125	210-250
Best Light	16,400	44,000
Long Life	30,000	94,000

T-4½ Bulb, ¼ and ½ Watt
Candelabra Screw Base
Types NE-45 and NE-57 (¼ Watt),
NE-58 (½ Watt)

These screw base lamps have resistors built into the base and may be connected to circuit voltage indicated.

T-2 Bulb, 1/25 Watt
Telephone Slide Base
Type NE-3

Small in diameter and tipless for good end-on effectiveness. Used in slide base pilot lights, these lamps extend the voltage range to commercial circuit voltages. Maximum with incandescent lamps is 60 volts. Require external resistor.

Recommended Resistance Values (Ohms)

Applied Volts	105-125
Best Light	56,000
Medium Life	100,000
Long Life	220,000

S-7 Bulb, 1 Watt
Double Contact Bayonet Base
Type NE-79

The most effective neon lamp-suitable for adverse conditions in heavy duty Pilot Lights.

Recommended Resistance Values (Ohms)

Applied Volts	105-125	210-250
Best Light	3,000	9,400
Long Life	6,000	60,000

T-2 Bulb
Midget Flange Base
Types NE-2D, NE-2J

Subminiature units for use in miniature indictators. Require external resistor.

Recommended Resistance Values (Ohms)
For NE-2D

Applied Voltage	105-125 AC or DC
Best Light	56,000
Medium Life	100,000
Long Life	220,000

For NE-2J (High Brightness)

Applied Volts	105-125 AC only
Best Light	18,000
Medium Life	33,000
Long Life	82,000

lens diameter, lens color, lens surface, terminal type, resistance value, metal finish and insulation. For example, Dialight Corp. offers for one body type adaptable to a T-3¼ neon glow lamp: 3 types of terminals, 6 types of screw-on lenses, 4 types of friction fit lenses and 16 types of screw-in lenses.

Choice of the modular elements is indicated by the function the pilot light will be required to perform.

Pilot light types as assemblies may be categorized generally as follows: sub-miniature, ultra-miniature (datalites), oil-tight, placard lights, press-to-test, press-to-switch, light shields, and dimmer types. Dialight also catalogs message lights, lens cap assemblies for panel mounting, bracket mounted sockets and lamp holders, and open type indicator lights. • • •

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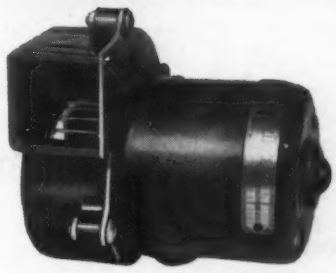

D2½S Single Blower

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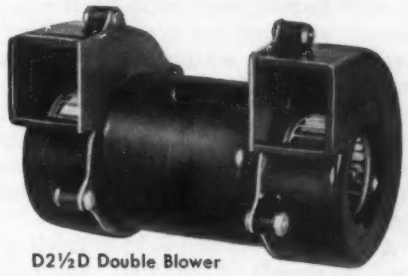

D2½D Double Blower

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MICROMINIATURE CIRCUITRY I

Thin-Film Components for Integrated Circuits

The possibility of applying thin-film techniques to the production of high performance electronic circuitry has reached a breakthrough point. Dozens of well known, well established components and systems groups have entered the fields with varying degrees and approaches within the past few years. And the potential of success and the state of the art is such that fully functional electronic modules based on this film components may be around the corner.

A newcomer to this field is Intellux, Inc. of Reseda, California. Although management has plans for a rotary components division and a military system division their main emphasis today is in the area of thin film techniques. Here is a report on the state-of-the-art, as engineers of Intellux see it.

Present available techniques for creating thin films with specific electronic characteristics are:

- Physical methods such as vacuum deposition and cathode sputtering;
- Mechanical methods such as rolling, spraying and cladding;
- Chemical methods, including thermal decomposition, electroplating, hydrogen reduction, and chemical reduction.

Of these the most used at this time are: vacuum deposition, electroplating, chemical reduction, and thermal decomposition.

Vacuum deposition involves placing the surface to be coated, the substrate, in an evacuated chamber, with a small quantity of the coating material. The coating material, subjected to intense heat, vaporizes and deposits on the substrate. This process, in general use and well developed, requires expensive equipment. Because films deposited have wide variations in the electronic and physical properties, the process does not seem to hold much promise for low cost, mass production.

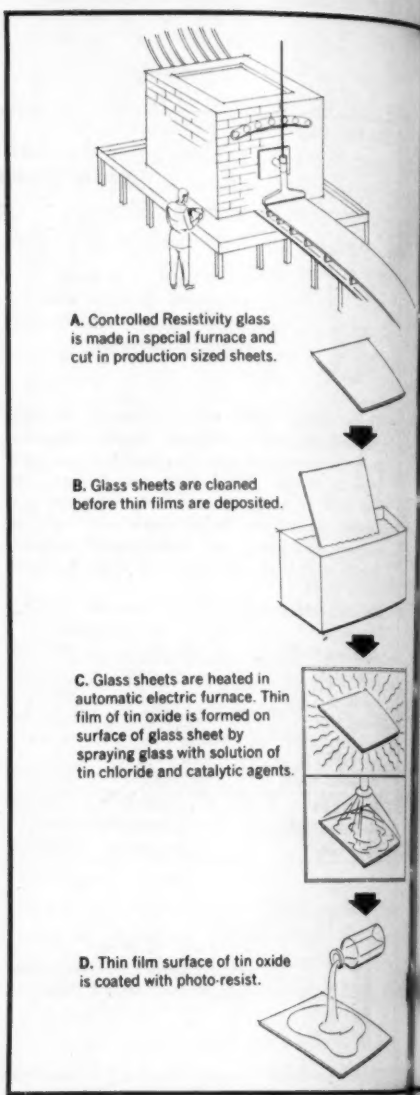
In electroplating, the substrate immersed in the plating solution functions as a cathode when current passes through the bath. The corners or sharp edges of the substrate represent high current density spots where the plating will be thicker, making it difficult to obtain uniform thin deposits, especially in fine line configurations. Moreover, to act as a cathode, the substrate must have electrical conduction characteristics—a major disadvantage in some applications.

If the substrate material is a non-conductor, previous metalization of its surface is required, resulting in variations in plating characteristics because of differences in metalizing thickness and the restriction of plating to metals alone severely limits film properties obtainable.

Chemical reduction techniques for the deposition of metal thin films were developed to a large extent by the National Bureau of Standards. The process consists of immersing substrate material in a bath of metal salts, an active chemical reducing agent (organic or inorganic) and a complexing agent. Metal salts provide the cations of the metal in solution; the reducing agent brings about the discharge of the metal ions. The complexing agent serves a two-fold purpose: it keeps the metal salts in solution in the form of complexes as the bath becomes acidic, and it serves as a buffer to keep the pH of the bath from changing too rapidly during the plating operation. The "electroless" metal films produced by chemical reduction are not pure metals; they contain small percentages of other materials such as phosphorous. Moreover, their physical characteristics are somewhat different from the properties shown by the same material deposited electrolytically.

While the process can be run at room temperature, controlling most of the variables, the chief drawback is that limited characteristics are obtainable from the few films that can be deposited chemically. However, because a chemical process can be automated for large quantities of film cheaply and quickly, Intellux, Inc. is devoting a R & D program toward its improvement. Since the chemical reduction process is specifically adapted to producing metal films, the investigation is directed at the applicability of the process to producing magnetic memory elements.

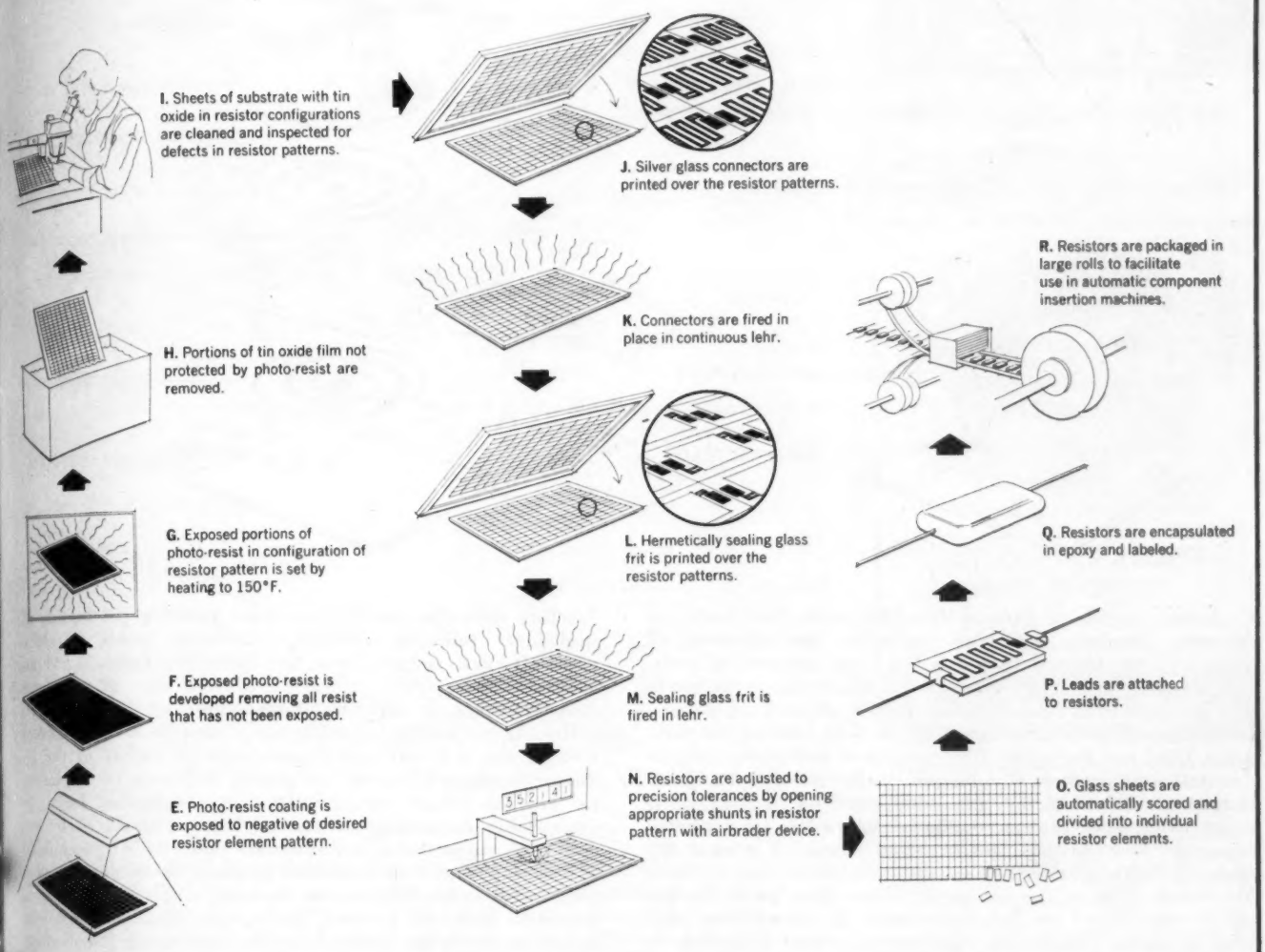
Thermal decomposition of thin films has been developed by Intellux to produce resistors, capacitors, and functional electronic units. Ferrite films have been deposited and are being investigated for suitability as memory elements including the deposition of a thin film diode that shows promise for computer applications.


A. Controlled Resistivity glass is made in special furnace and cut in production sized sheets.
B. Glass sheets are cleaned before thin films are deposited.
C. Glass sheets are heated in automatic electric furnace. Thin film of tin oxide is formed on surface of glass sheet by spraying glass with solution of tin chloride and catalytic agents.
D. Thin film surface of tin oxide is coated with photo-resist.

THERMAL DECOMPOSITION PROCESS

Thermal decomposition can be applied to a number of different materials, resulting in thin films that can satisfy numerous electronic functional requirements. The inherent physical characteristics of the deposited films and the materials chosen as substrates form the basis for the excellent weight and space characteristics and high environmental resistance. The films themselves are compatible with modern photo-chemical processes which make possible highly efficient production and low unit cost.

In thermal decomposition, films are formed by spraying the surface of a heated substrate with a solution of the film material and catalytic agents. The materials in solution decompose when exposed to the high temperature substrate and form chemi-molecular bonds with the substrate surface material to


I. Sheets of substrate with tin oxide in resistor configurations are cleaned and inspected for defects in resistor patterns.
J. Silver glass connectors are printed over the resistor patterns.
K. Connectors are fired in place in continuous lehr.
L. Hermetically sealing glass frit is printed over the resistor patterns.
M. Sealing glass frit is fired in lehr.
N. Resistors are adjusted to precision tolerances by opening appropriate shunts in resistor pattern with airbrader device.
O. Glass sheets are automatically scored and divided into individual resistor elements.
P. Leads are attached to resistors.
Q. Resistors are encapsulated in epoxy and labeled.
R. Resistors are packaged in large rolls to facilitate use in automatic component insertion machines.
H. Portions of tin oxide film not protected by photo-resist are removed.
G. Exposed portions of photo-resist in configuration of resistor pattern is set by heating to 150°F.
F. Exposed photo-resist is developed removing all resist that has not been exposed.
E. Photo-resist coating is exposed to negative of desired resistor element pattern.

Resistors produced by the thermal decomposition technique above have outstanding properties of accuracy, stability, and ability to perform under high temperatures. Tin oxide thin films are used with a basic resistivity of 100 ohms per square. Value of resistor is determined by controlling the length to width ratio of the film configuration. Range of resistance available with tin oxide films is roughly from 20 ohms to 2 megohms. Extensions of these ranges can be made by altering the basic resistivity of the thin film; power rating of the resistors is determined by the overall size of the element configuration. Resistors are coated with a glass frit that is fired to provide optimum hermetic sealing. Intellux, Inc., is presently producing resistors by this method to comply with all requirements under Mil Spec 10509C in production runs, 800 ¼" x ½" or 3200 ⅛" x ¼" resistor elements are formed simultaneously on a single 10" by 12" glass substrate.

Thin film resistors formed by the Intellux process have the following characteristics:

Resistivity: 100 ohms per square.
Minimum value: 50 ohms.
Maximum value: 4 megohms.
Temperature coefficient: 30 PPM/C
Voltage coefficient: none.
Inherent accuracy: 8%.
Accuracy after adjustment: 1% (0.1% with special precautions).

Resistance change: 1 to 4% estimated after 1000 hrs period of aging at 500 C, 0.1% to 0.2% after humidity cycling, 0.1% after five-year shelf life, 0.5% maximum at 100% load at 125 C ambient. Dissipation: 1 watt per 1 square inch will cause temperature rise of 35 F at 70 F ambient.

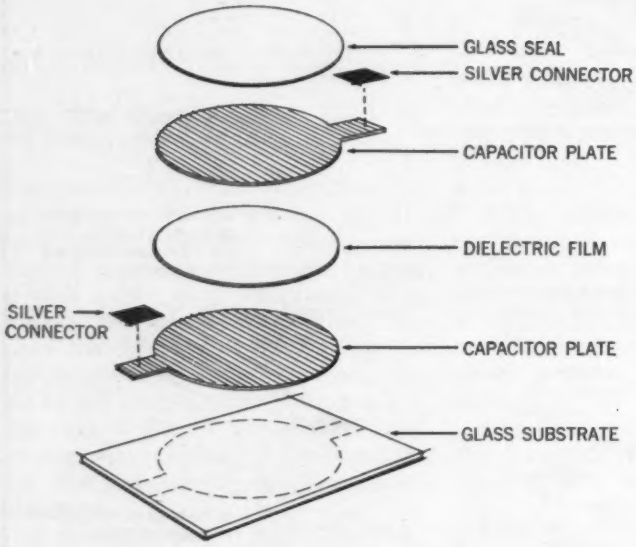
produce films approximately ten millionths of an inch in depth.

Electronic properties of these films are, of course, dependent upon the original materials used and the catalytic agents employed.

Once formed on the inert, dimensionally stable substrate, the film has uniform electronic properties. Utilization of these uniform properties in a specific electronic element requires that the film be processed to provide a definite two-dimensional configuration. That gives the elements their desired values.

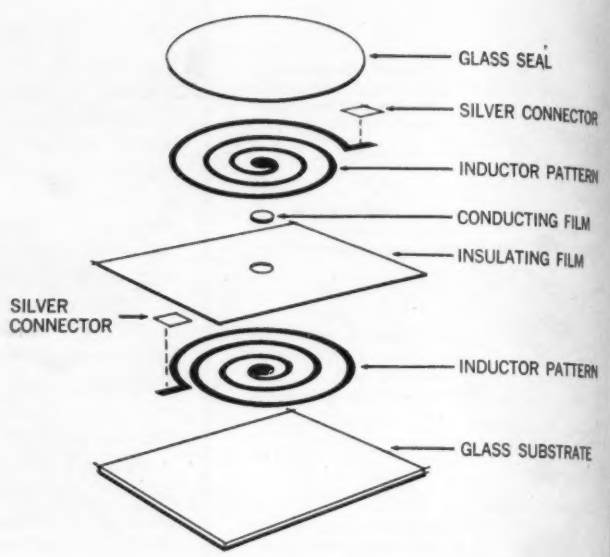
PHOTO-CHEMICAL PROCESSING

The thin film coated substrate is covered with a photo-sensitive material, which, when exposed to light, becomes impervious to certain chemical reagents; unexposed portions can be dissolved away by reagents. The result of these processing steps is a substrate with a thin film of selected material deposited on its surface in certain desired configurations. Production resolution obtainable with this process can produce line widths of 0.0015 ±0.0001 inch. Line widths as fine as 0.0004 inch have been produced in limited quantities. These configurations of thin films form the basic electronic elements.



Exploded view shows various thin film layers that make up capacitor elements. Individual capacitors and networks of capacitors are formed in much the same manner as resistors. Initial steps in the process are the same: a tin oxide film in the desired configuration for the plate of the capacitor is formed on a glass substrate by first coating the substrate with the tin oxide film and then processing photochemically to produce the desired configurations. An insulating, high dielectric, thin film, developed by Intellux, Inc., is deposited over the tin oxide configurations and photochemicaly processed to the required shape. A second tin oxide fim is then laid down over the dielectric film to form the second plate of the capacitor. Silver glass paste for external connections or interconnections is printed on and fired in place. Finally, an electronically inert glass frit is spread over the capacitor and fired to hermetically seal the unit. Capacitors produced by this technique have the following general characteristics:

- **10,000 micromicrofarads per square centimeter maximum**
- **0.01 micromicrofarads per square centimeter at 50 volts using a non-conducting iridized oxide film, 0.001 inch thick, as the dielectric**
- **0.01 micromicrofarad capacitors with temperature coefficient similar to mica capacitors.**



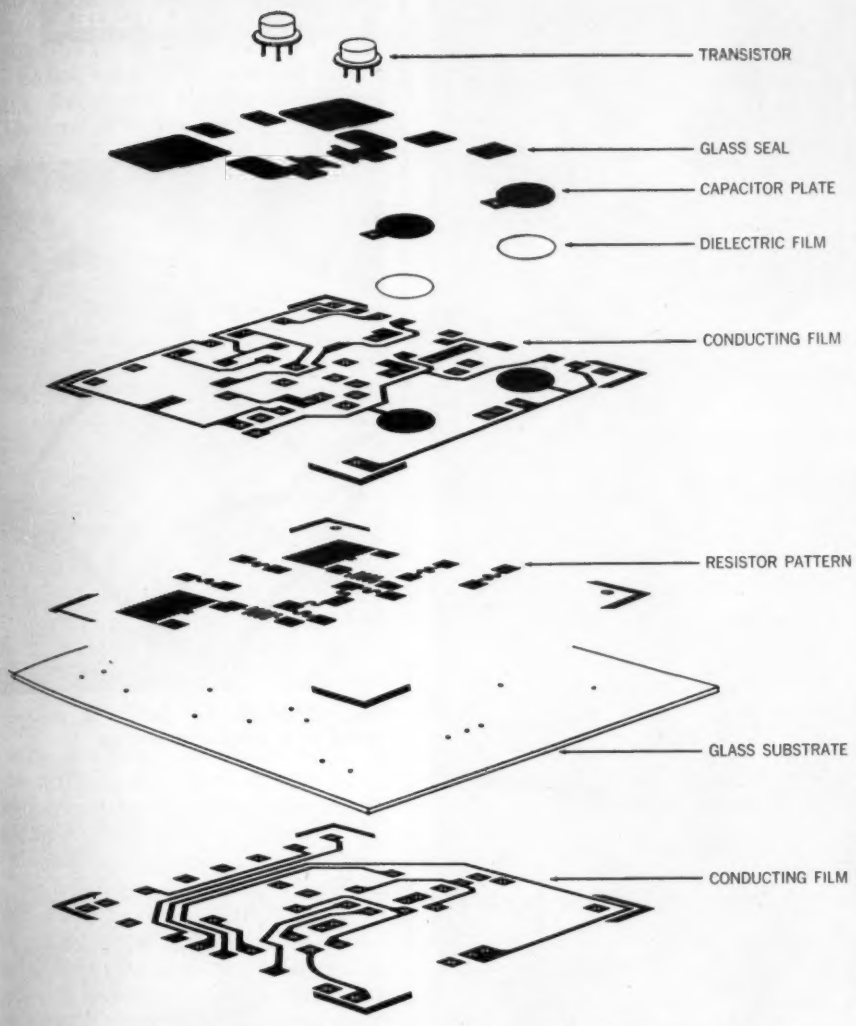
Intellux thin film techniques make possible production of multilayer inductor elements. Alternate layers or right- and left-hand spirals form the inductor. Insulating films separate the spirals. Inductors present one of the most difficult areas in microminiaturization of electronic circuitry. Inductance is determined by the physical configuration of the inductor and factors such as radius of the inductor, number of turns, and radial thickness of the inductor are the major considerations. An important factor in deposited inductors is, of course, losses introduced by the dielectric properties of the substrate material. The technique of forming deposited inductors involves the deposition of a high conductance film in the form of a spiral. Single layer inductors have, in general, low values of inductance, and several methods are under study for increasing these values. One concept involves additional deposition of a magnetic material in the center of the spiral configuration. Another is to deposit a second spiral of magnetic material interwined with the inductor spiral. The thin film deposition techniques employed by Intellux, Inc., permit another approach to increase inductance value: producing multi-layered inductors of alternate right- left-hand spirals suitably interconnected. Thin films of insulation separate the alternate spirals.

Several individual configurations can be formed in this manner on one segment of substrate and interconnected to form networks of electronic elements, but, more important, the entire process can be repeated with films of different electronic properties to form combinations of electronic elements to be used individually or combined for some single electronic function. Combinations of configurations of these resistive, dielectric, conductive, and magnetic thin films, then, can be used to produce units that perform a variety of electronic circuit functions. For high-density packaging, these films, separated by insulating layers, can be "sandwiched" to any depth desired—and interconnected by other deposited films.

Besides demonstrating excellent electronic properties, Intellux claims these films have the advantage of being only ten millionths of an inch thick and thereby contribute a negligible amount to the weight and volume of the final electronic unit. In addition, because of the high temperatures of the production process, the resulting films are operative at temperatures that greatly exceed operating thermal ranges of the majority of present day electronic equipment. Thin film units also lend themselves to encapsulation with ceramic materials, providing maximum sealing against adverse environments.

FUNCTIONAL ELECTRONIC UNITS

Investigations into the application of thin film techniques to basic electronic elements indicate the great similarity of the process steps required to form each type of basic element. It is this consistant procedure that gives the thermal decomposition technique its greatest advantage in generating functional electronic units. Thin films used for the various electronic properties are all compatible, have the same temperature requirements in production, can all be processed photochemically,



Exploded view shows relationship of various thin film elements used in functional electronic unit. Initial functional units developed will use thin film resistors, capacitors, and inductors and commercially available cased and uncased active elements. Active elements will be connected to thin film circuit and entire unit hermetically sealed in glass. Advanced development underway at Intellux is directed at producing thin film rectifying and amplifying devices that will be deposited along with passive elements eliminating need for conventional semiconductor devices.

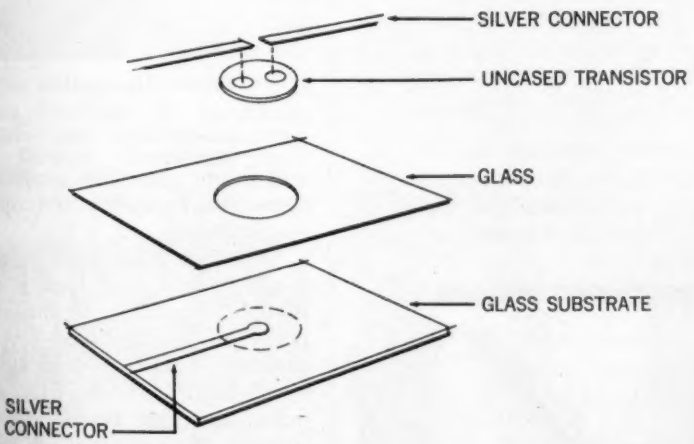


Illustration shows method of connecting uncased transistor element to thin film functional unit. Uncased transistor is inserted into depression in glass substrate where transistor makes contact with conducting film. Connections to active sections of transistor are made by depositing conducting films over these sections. Exposed surfaces of the transistor are then passivated to prevent contamination and the unit is hermetically sealed in glass.

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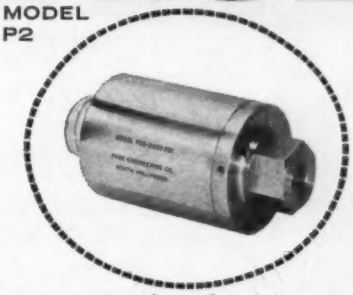

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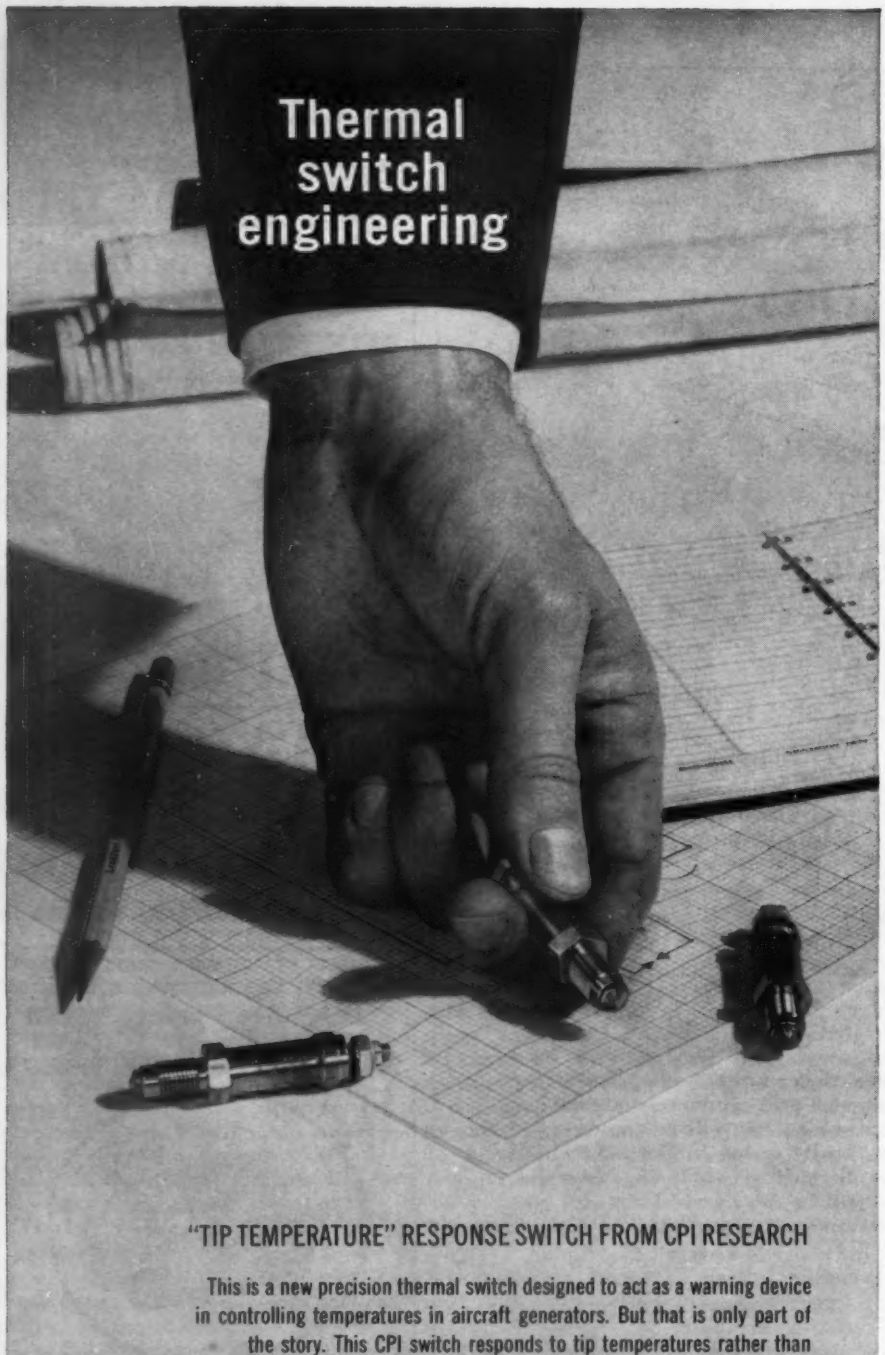

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This is a new precision thermal switch designed to act as a warning device in controlling temperatures in aircraft generators. But that is only part of the story. This CPI switch responds to tip temperatures rather than shell temperatures. For that reason it's called the "Tip-Stat". It now joins the growing CPI family of high quality, custom, precision thermal switches.

There's a good chance that this switch or a modification of it can solve your thermal control problems. If not, CPI engineers can create a new switch that does. In either event, why not tell us about your thermal control problem now?

This hermetically sealed switch has spring loaded inner cartridge, can be "bottomed" in hole under considerable tip pressure; calibration range is −20F to 550F; safe momentary overshoot to 600F; reaction time, less than 0.5 seconds. Mention "Tip-Stat" when inquiring.

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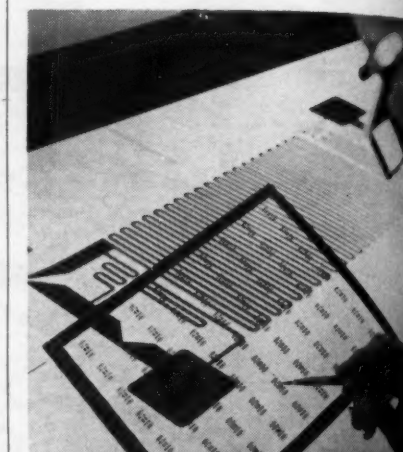
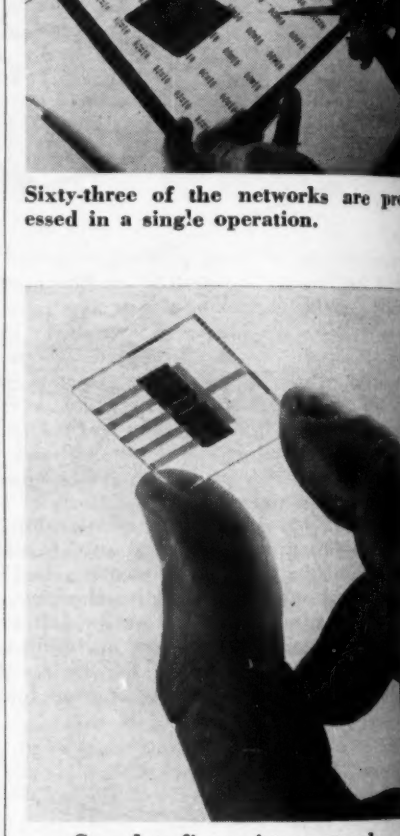


Sixty-three of the networks are processed in a single operation.



Complete five-resistor network.

and exhibit excellent qualities such as dimensional stability and resistance to contamination.

Transition from these individual elements in functional units is more than feasible. According to Intellux it is already an accomplished fact. Resistor-capacitor filter networks have already been fabricated. A computer clock pulse generator circuit employing 15 resistors, 2 capacitors, 6 diodes and 4 transistors is currently in development.

These accomplishments form the incentive for this proposal and assure the production of functional electronic

units in time to satisfy Naval requirements.

The typical functional unit envisaged by Intellux consists of multiple layers of thin film passive electronic elements interconnected by conducting films and separated where necessary by insulating films. Cased or uncased microminiature active elements such as diodes and transistors would be mounted on or in depressions in this multiple layer sandwich and connected to appropriate portions of the passive element networks by silver inks or conducting thin films. The entire unit would be sealed in a glass frit to prevent contamination of the uncased elements and to hermetically protect the entire unit.

APPLICATION TO COMPUTER DESIGN

One of the promising areas for the application of thin-film modules lies in reducing the size, weight, maintenance, reliability and cost of computers. Functional modules, interconnected in accordance with the logical design of the specific computing requirement, can provide computer designers with a wide flexibility in logical design without the necessity for developing basic circuitry for each new computer.

computing requirement and the pro-

The technique greatly shortens the lead time between establishing the duction stages, since it eliminates the need for long periods of circuit design that must be completed before production can be started. In addition, once the basic functional modules have been selected, continuing development can be concentrated on increasing their reliability, and reducing their cost without requiring any major modifications of the computer logical design.

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MICROMINIATURE CIRCUITRY II

Continuous Pattern of Tantalum Components and Interconnections Provides Circuit Simplicity and Homogeneity

Considering reliability, size and cost as the key design objectives, Mr. D. A. McLean of Bell Telephone Labs, Murray Hill, N.J., evaluated the potential of tantalum microcircuitry in a paper presented at the recent National Electronics Conference.

TANTALUM FILMS

At the Bell Laboratories, the method being developed for general purpose microcircuitry consists of first producing a pattern of tantalum on an inor-

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CIRCLE NO. 40 ON INQUIRY CARD

Fig 1 Internal and external connections of a pyrolylic carbon resistor. There are eight junctions, four at each end: (A) between the carbon coating and the silver or other contacting material; (B) between (A) and the metal cap; (C) beween the metal cap and the external lead; (D) the connection into the circuit. None of the eight junctions are required when tantalum microcircuitry with tantalum resistors is employed.

ganic substrate. Appropriate sections of the pattern are anodized to form the dielectric for capacitors. Resistors are a part of the pattern consisting of lines of appropriate length and width. Tantalum also forms the basic interconnections which can be overlaid if necessary with a metal of higher conductivity. Thus in one continuous pattern produced by a simple series of steps the capacitor anodes, the resistors, the conducting paths and the interconnections are integrally formed.

Metals other than tantalum are contenders for this type of circuitry; for example, niobium, titanium and zirconium. Bell Lab's choice of tantalum is based on its high potential usefulness; on Bell's extensive background in the production and use of tantalum oxide dielectric films; and on the availability of tantalum in high purity.

Mr. McLean reported that attempts to produce tantalum film components on ordinary ceramic surfaces have been generally disappointing. Capacitors so made usually have poor dielectric strength and the resistors are difficult to control due to variable substrate surface characteristics. Greatest success has been achieved on glass surfaces although glazed ceramics hold some promise. The bulk of Bell Lab's exploratory work has been with ordinary soda-lime glass, but success has also resulted with Pyrex, Vycor and Fotoform.

The reason for the limited usefulness of ordinary ceramic surfaces probably lies in the fact that the surface irregularities are very large compared with the thickness of the tantalum films. Methods may be found for lapping or polishing ceramics to give a satisfactory surface, but in the meantime Mr. McLean declared, it is necessary to rely on glass or on other materials having equivalent surface smoothness.

DEPOSITION METHODS

Tantalum films may be deposited by sputtering or evaporation. Sputtering is convenient for laboratory use since it is essentially a low temperature process. At Bell Labs, it is carried out in argon at a pressure of 10 to 20 microns and at a potential of about 3500 volts between electrodes with 2.5″ spacing. Under these conditions, the sputtering rate is about 100 A.U. per minute, although by increasing pressure and voltage, higher rates can be realized.

Initial sputtering is on a shutter which is swung out of the way after sputtering conditions are established. Arc-melted tantalum is used for the cathode. When applying films to individual substrates little is gained by increasing sputtering rate since most of the cycle time is involved in pumpdown and other preliminaries. In either evaporation or sputtering for commercial uses it would be desirable by internal feed mechanisms or by other means to arrange for coating a number of substrates per cycle.

In carrying out evaporation of tantalum at reasonably high rates, it is necessary to raise the charge to a temperature in excess of 3000C. This is accomplished most conveniently by electron bombardment. At Bell, substrates have been coated at a rate of 500 A.U. per minute when placed 4″ from the source and there is every reason to believe that higher rates can be achieved.

The readiness with which high rates can be obtained by evaporation; the fact that the charge is degassed and purified at high temperature; and the carrying out of the process in high vacuum—all make evaporation a serious contender as a commercial method of application. In evaporation as in sputtering, a shutter can be used to collect the first material to come from the charge.

One of the most critical tests of adhesion is the ability to anodize without peeling the film from the substrate. Except in the cases of known substrate contamination, no adhesion difficulties have been observed either with sputtered or evaporated films.

CAPACITORS

Electrochemically-produced tantalum oxide is used as the dielectric in capacitors. In the formation of the dielectric, the tantalum film is made positive in an electrochemical cell to convert a part of the metal to Ta_2O_5. The capacitor is completed by depositing a counter-electrode of gold, aluminum or other suitable metal on top of the oxide. The thickness of tantalum oxide formed is directly proportional to the voltage used in anodizing if other conditions are kept constant. For room temperature formations, the thickness is about 15 A.U. per volt. The films formed are extremely uniform and readily controlled in thickness to near-atomic precision.

Dielectric strength of tantalum oxide layers formed electrochemically on tantalum deposits is about 6×10^6 volts per centimeter and the working stress about one-half of this. The working voltage is 7500 volts per mil. Dielectric constant of tantalum oxide is about 25. Capacitors for 50 volt operation provide approximately 0.1 cm^2 or 1000 pf/mm^2. Indeed, one problem is that the value is so high that high precision area control is required for small valued capacitors. However, this high area yield means that it is practical to build most microcircuit capacitors as simple single layer items.

At 75 volts, leakage is of the order of 10^{-9} amps for a 30,000 pf, 50 volt capacitor. This corresponds to 2000 to 3000 ohm farads (although measured at 50% above working voltage). Tantalum oxide has a dissipation factor of 0.01 or less, the exact value depending upon tantalum purity and other factors. Up to several hundred KC, there is little change in dielectric constant or dissipation factor with frequency. Data are not yet available in the megacycle range. In high-valued capacitors, there is a possibility of the high frequency

properties being controlled by the effective series resistance of the electrodes. This can be overcome by employing an underlay of conducting metal. The series resistance can also be minimized in the capacitor design, especially for small capacitance values, by careful attention to shape. Temperature coefficients are quite consistently in the range of +250 ppm/C.

Life tests are limited at present and further extensive tests will have to be made to establish reliability. The nature of the materials used and the fact that dielectric properties approach the intrinsic properties of the materials indicate that high reliability should be realized. In the largest life test to date, sixty-seven 50 volt, 30,000 pf capacitors were placed on dc potential at 50 volts and 85°C. In an 18 week test there was one failure which occurred at 14 weeks. At 90% confidence level, this corresponds to a failure rate of less than 2% per 1000 hours, under these severe conditions.

RESISTORS

Tantalum is also an excellent material for film resistors. Sputtered or evaporated tantalum films have resistivity values 10 to 40 times of that of bulk tantalum. This places tantalum films in a resistivity range with bulk nichrome. Temperature coefficients of resistivity are generally bracketed by the range ±150 ppm/C. Values within this range appear somewhat randomly but it is believed that with further development, control of temperature coefficient will be possible.

Tantalum film resistors can be adjusted by anodizing since this process converts a controlled amount of metal into insulating oxide. Furthermore, in most ranges, the resistance can be monitored during adjustment so that the process can be stopped at exactly the right point. The anodic film provides both chemical and mechanical protection and is therefore useful even when not employed for adjustment.

Like most metallic film resistors, tantalum film resistors require thermal aging to stabilize them. The exact nature of the stabilizing process is not known, but appears to involve both structural and compositional effects. If the tantalum resistors are to operate up to 100°C, a stabilization treatment of several hours at 200 to 300C is used and this always produces an increase in resistance.

INTERCONNECTIONS

A feature of tantalum microcircuitry is that as far as possible connections internal to the board are tantalum films. These will usually be stripes of tantalum which are wide compared to the resistor line width, but it is also

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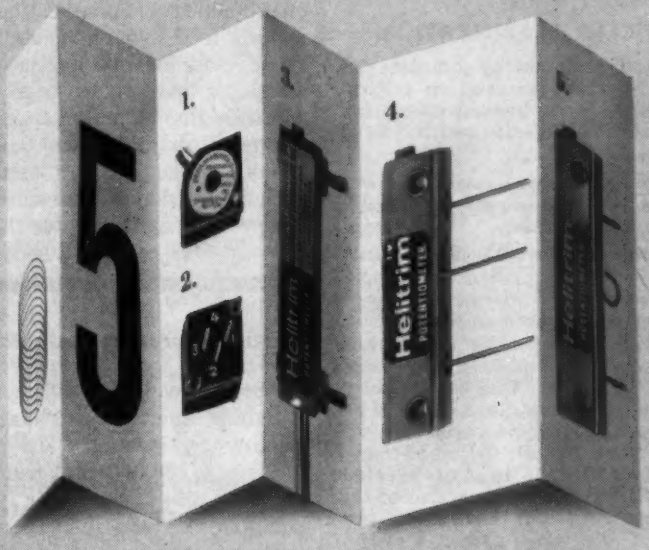

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why

PERMANENT MAGNETS ARE PERMANENT!

TRULY PERMANENT permanent magnets are now possible, according to scientists of Indiana Steel Products Division, Indiana General Corporation. The following conclusions were gained during a special research project conducted by Indiana and supported by funds of the United States Air Force.*

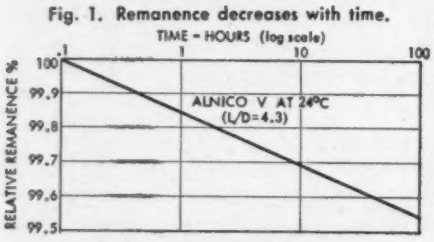
NATURAL STABILITY

1. Materials having the highest coercive force displayed the greatest natural stability.

2. Rods of ALNICO V having a greater length-to-diameter ratio proved more stable.

3. Where change in remanence was perceptible, it was found that it decreases linearly with the logarithm of time. (See Fig. 1.)

Fig. 1. Remanence decreases with time.



TEST CONDITIONS

Sample magnets under study were kept in a special room where they were relatively free from external demagnetizing influences. Temperature was kept virtually constant at 24° +2.5°C. The sensitive measuring apparatus, also located in the test room, permitted measurements to an over-all tolerance of better than 1 in 10,000.

ARTIFICIAL STABILIZATION

Two methods of achieving complete stabilization — often required in critical applications — were proved successful. Both involved artificial reduction of remanence.

Temperature Knockdown—several cycles of low temperature exposure, to −65°C, produced the greatest stability.

Knockdown by Applied AC Field—magnets were subjected to a cycling diminishing field. Stability was best achieved when remanence was reduced to between 5 and 15%.

This study indicates that permanent magnets *can* be completely stabilized. A magnet, however, that is perfectly stable under test conditions can still be affected by temperature variations, vibrations, stray magnetic fields and many other factors. In the case of selected magnets, stability *can* be guaranteed for a flux change no greater than 0.01% per year.

For complete information on the practical aspects of "stability," and for a summary of experimental results, ask for a copy of Applied Magnetics, First Quarter, 1959. Write Dept. V-12

*Contract AF33 (616) — 3385 monitored by the Aero. Res. Lab., WADC.

DIVISION OF INDIANA GENERAL CORPORATION

INDIANA STEEL PRODUCTS
VALPARAISO, INDIANA
In Canada: The Indiana Steel Products Co. of Canada Limited, Kitchener, Ontario

INDIANA PERMANENT MAGNETS

CIRCLE NO 68 ON INQUIRY CARD

possible for the interconnecting lines to form a part of the resistor pattern. In many instances it will not be necessary to increase the conductance of the interconnecting lines. However, when required, conductance can be enhanced by overlaying the tantalum interconnections with a more conducting metal such as aluminum or gold. This can be done at the same time that counter electrodes are applied to the capacitors, but even when this is done, the basic underlying layer of tantalum is always present.

ACTIVE ELEMENTS

For transistors and diodes, standard items are used and either plugged or soldered into place. This aspect is being further developed since it is essential to devise active elements in housings which are compatible in shape and with current microcircuit developments. This, Mr. McLean noted, is one of the most pressing needs of current microcircuitry of all types.

OVERALL EVALUATION

Process simplicity of tantalum microcircuitry arises from the fact that the essential passive components and interconnections are laid down in a single pattern by a simple sequence of steps. Mr. McLean stated that a system based on simple well understood materials and produced with a minimum of manufacturing complications will obviously lead to high reliability and low cost. Absence of boundaries between materials, particularly the boundaries between dissimilar materials minimizes the need for solder, welds, or other interconnections of questionable integrity. Fig. 1 depicts the unions, usually between dissimilar materials, in a common deposited carbon resistor. None of the junctions depicted in the figure are required in tantalum microcircuits. Homogeneity might be considered the key feature of tantalum microcircuitry since it has an important bearing on all three major objectives: reliability, size, and cost. Elements can be packed closely together thus keeping size down. Cost is minimized since most interconnections are made as an integral part of the process. In figuring the cost for tantalum microcircuitry, it will not be possible to separate out the cost of capacitors, resistors and assembly since all are made simultaneously and integrally. Cost comparisons will have to be based instead on subassemblies.

Tantalum is well known for its chemical inertness. Hopefully, this means stability without hermetic seals or other protection with the possible exception of anodic oxide film.

Tantalum microcircuitry is not aimed at ultra high temperature applications. Particularly without hermetic sealing, tantalum reacts with atmospheric gases at about 300C and above. Furthermore, even if hermetically sealed, tantalum oxide films on tantalum degrade at temperatures above about 400 to 500C. If one were striving to meet ultra high temperature requirements, it would be desirable to explore tantalum alloys or entirely different metals to which the same concepts of homogeneity and structural and process simplicity could be applied.

Mr. McLean referred to tantalum microcircuitry as only the beginning of an approach which may result in application of similar concepts to a number of other materials in order to meet specialized requirements. • • •

Portable Aircraft Weighing Kit

Electronic weighing kit is capable of weighing any aircraft (and for determining cg location) up to a gross weight of 150,000 lbs., from forces exerted at three measuring points. The complete kit contains a transistorized indicator, a power supply, three load cells each with a 50,000 lb. capacity, three 50 foot length cables and spools, three adapter rings and plugs, three power cables, molded plastic carrying case, a metal operation instruction plate and an optional accessory kit. All equipment is shock-mounted within the carrying case. Baldwin-Lima-Hamilton Corp., Waltham, Mass.

Write No. 334 in Box on Inquiry Card

Ultrasonic Joining Unit

Emitting high-pitched, silent sound waves at 25,000 cycles per second, an ultrasonic device joins materials previously considered extremely difficult or impossible to "wet" with fluxless solder or weld. The materials such as aluminum, silicon, germanium, and ferrites, are considered difficult to join because of the oxide film which forms on their surface. Solder without flux cannot penetrate this film to "wet" the surface. Sound waves excite molten solder on surface of these substances and break down oxide film. Portable unit operates on power input of 115 volts ac. Raytheon Co., Norwood, Mass.

Write No. 626 in Box on Inquiry Card

by David Bandel *Staff Columnist*
Associate Technical Director,
TRACERLAB, INC.

MATERIALS

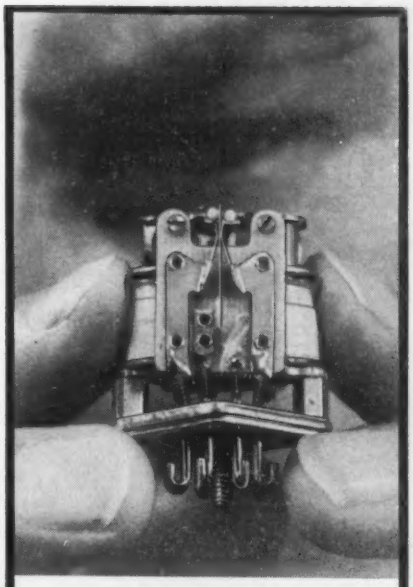
Thermoelectric power is beginning to compete actively in applications generally reserved for chemical power packages. The new high efficiency thermoelectric elements have made this competition possible. Minnesota Mining and Manufacturing Co. has delivered a thermoelectric power source to the Coast Guard for evaluation as a power source in navigation aids. The thermoelectric generator is fueled by liquid propane, or "bottled gas". Power output from this package is 10 watts, and it is claimed that 200 watt hours can be delivered by each pound of propane fuel. The potential advantages of this power package are reduced frequency of replacement and lower costs. Chemical batteries produce power at $6-10 per kwh. Propane fuel will deliver power at $0.15 per kwh, which is a very substantial cost differential.

The attractive possibilities of obtaining electric power directly from heat has stimulated search for more efficient thermoelectric materials. R. C. Vickery and his associates at NuCor have recently reported on the thermoelectric properties of gadolinium selenide. This material shows a Seebeck coefficient of 600uV/degrees C at 800 degrees C., which is the highest found to date. Gadolinium telluride may show an even higher Seebeck coefficient but no work with this material has been reported as yet. It is claimed that gadolinium selenide will operate at temperatures above 1000 degrees C, which is higher than the operating limits of present day high efficiency thermoelectric materials, such as lead telluride. The thermoelectric figure of merit for gadolinium selenide is $4x10^{-3}$.

A new photoemissive material for high temperatures has been announced by Westinghouse. A high level of photosensitivity can be maintained at temperatures of 250 degrees F for many hours. Present photoemissive materials do not operate at temperatures above 140 degrees F. In addition to improved thermal characteristics, the "dark current" of the new material is less than 1% of conventional photoemissive materials, resulting in less "noise" and increased sensitivity. In place of the usual cesium photocathode, the new photoemissive surfaces are made of sodium and potassium combined with antimony. Photoresponse values up to microamperes per lumen have been recorded for some experimental compositions. Photosensitivity decay constants of $0.34x10^{-3}$ have been obtained at 250F, corresponding to a decrease of 7% after 100 hours. Measurements of spectral response before and after operation at elevated temperatures show that the decay in photoelectric yield is not constant at all wave lengths and is least in the region of 420 millimicrons.

A radiation resistant solar cell has been developed by the Army. It is claimed that the radiation resistance of the new cells is more than 10 times higher than present cells. The new cells are made by diffusing phosphorous into the surface of a p-type silicon crystal. Present solar cells are made by diffusing boron into n-type silicon crystals. The mechanism of the effect that produces radiation resistance is not known, but it is believed that this discovery may furnish new leads on methods of producing radiation resistant semiconductor materials, which are needed to power satellite electronics for long periods in orbit.

Dow Corning has announced a new mineral-filled silicone molding compound for service at 700F., for extended periods. In addition to outstanding thermal stability, this material has high arc resistance, over 400 seconds, and low dielectric losses.



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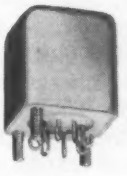

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contact arrangement	DPDT (2 form C)
contact rating	5 amps @ 26.5 VDC or 115 VAC 60 CPS resistive load
min. oper. power @ 25°C	VG: 340 milliwatts VGS: 125 milliwatts
max. oper. time @ nom. oper. power	VG: 6 milliseconds VGS: 20 milliseconds
max. release time	10 milliseconds
duty	continuous
shock	VG: 100G VGS: 50G (MIL-R-5757C, shock test II)
vibration	10-55 CPS total max. excursion of 0.060 in.; 15G, 55-2000 CPS
amb. temp. range	−65°C to +125°C
life	100,000 operations @ rated resistive load (MIL-R-5757C)
enclosure	evacuated @ 2.5 in. HG ABS, degassed @ 10 microns and 170°C, dry nitrogen filled & hermetically sealed
dimensions	H−0.875″; W−0.875″; L−1.125″
weight	1.5 ounces

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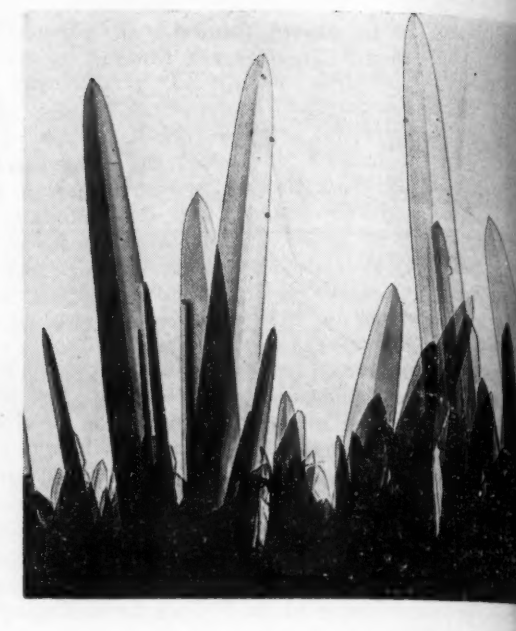


Taken at identical magnification through an electron microscope at the Westinghouse research laboratories, these two figures demonstrate the effect of water vapor upon the rusting of iron. In a dry oxygen atmosphere (left) the iron forms a protective oxide coating thickly populated with thin whiskers about 30-millionths of an inch high, each one growing from a specific site on the metal surface. But in an atmosphere of pure water vapor (right), the surface erupts into thin, blade-shaped oxide crystals, which reach a density of nearly one billion per square inch. The blades of oxide grow in size causing corrosion.

NEW THEORY FOR RUSTING OF IRON

Hydrogen Ions From Water Vapor Cause Destructive Reactions

Scientists at the Westinghouse Research Laboratories have advanced a new basic explanation for the corrosion of iron. Dr. Earl A. Gulbransen and T. P. Copan suggest that the true culprits are hydrogen ions.

The hydrogen ions come from water vapor, which must be present if iron is to rust to any great extent at room temperature. Their theory suggests that the tiny hydrogen particles penetrate the iron and enlarge the sites at which oxygen normally combines with the metal. This spreads the reaction throughout the surface of the iron, causing it to rust destructively.

Until now, the standard explanation for iron corrosion is that it is an electrochemical reaction, somewhat similar to that which occurs in an ordinary battery. Tiny local areas on the surface of the metal are assumed to act as plus and minus electrical terminals under the influence of an invisible liquid film of water, generating minute electric currents that corrode the iron. The new theory suggests that something more fundamental takes place in the iron, even though an electromechanical reaction also may be present.

In a series of experiments that eliminated the conditions required for electrochemical reactions, the Westinghouse scientists reduced the complex rusting of iron to its simplest atomic processes. Pure iron wires about as thick as a fine sewing thread were reacted with oxygen and water vapor at high temperatures (835 F) under closely controlled, idealized conditions. The results of the minute-scale corrosion were studied under an electron microscope capable of magnifying objects up to 300,000 times.

The scientists report that with dry oxygen the iron forms a protective oxide coating from which grow billions of tiny round oxide whiskers less than one-millionth of an inch in diameter and 30-millionths of an inch high. Each whisker grows from a single, specific growth site on the wire's surface, similar to that of individual seeds that sprout from the ground into separate plant stems. Then the wires were reacted under identical conditions except that water vapor was substituted for the dry oxygen atmosphere.

The moisture produces a startling change in the oxide surface. From the growth sites erupt thin, pointed, blade-shaped platelets of iron oxide that spread across the metal surface. Shaped somewhat like blades of grass, they are about one-millionth of an inch thick, 30-millionths of an inch wide and 300-millionths of an inch high. As they grow in size, they spread more than 50 times in area over the sites observed for dry oxygen alone, reaching a density of nearly one billion per square inch of surface area. The amount of iron rust they represent is 250 times that which forms when the water vapor, and the hydrogen ions it releases, are absent from the reaction.

The experiments by the Westinghouse scientists show that less than one part of water vapor in 200 parts of the dry oxygen atmosphere will cause the blade-shaped crystals to form. At room temperature this would correspond to a relative humidity of about three percent.

"We conclude that the hydrogen ions in the water vapor enlarge the area of chemical reaction between the oxygen and iron and bring about the metal's greatly increased corrosion," Dr. Gulbransen declared. "At the lower temperatures at which iron usually rusts, this basic reaction is masked. Complex corrosion products are formed and are not stable, and the corroding metal is often removed from the reaction site. Once such basic understanding is at hand, we should be able to do a much better job of controlling corrosion. Already we can identify two control measures which must be considered in addition to any electrochemical effects that are involved in iron rusting: hydrogen must be prevented from entering the metal; the growth of the localized reaction sites must be inhibited by the addition of suitable alloying elements to the iron." . . .

LOW TEMPERATURE ELECTRONICS

Negative Resistance Region In "Tunneltron" Extends The Range Of Cryogenic Circuitry

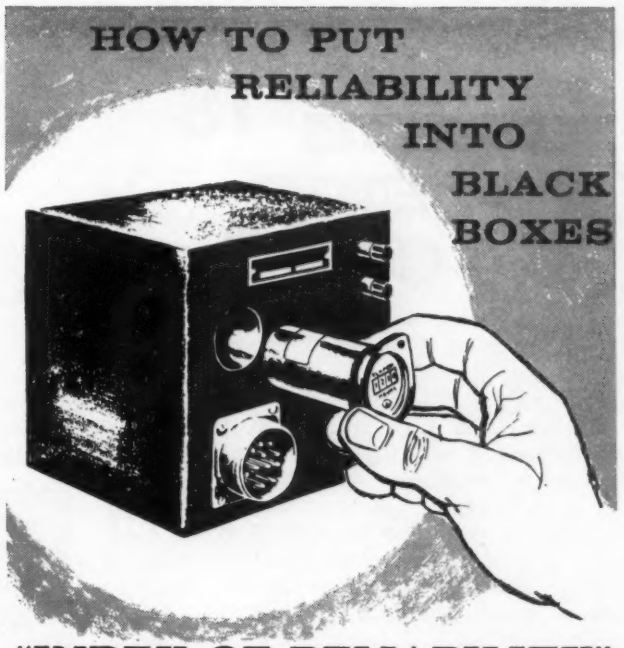
Physicists at Arthur D. Little, Inc., Cambridge, Mass. have discovered a low temperature phenomenon that may push electronic micro-miniaturization into new phases of flexibility, dependability and compactness. Dr. James Nicol, Dr. Sidney Shapiro and Paul H. Smith observed an unexpected "switch-back-action" or negative resistance region when current was passed through a metal-dielectric-metal sandwich at temperatures approaching absolute zero. Application of this negative resistance phenomenon is expected to lead to the development of a whole new family of simply constructed components compatible with present low temperature electronic circuits such as cryotrons. The new devices, called tunneltrons, may extend the range of cryogenic circuitry to include low noise amplifiers, high frequency oscillators and new types of switches and memory devices for computers. The tunneltron has extremely low power requirements and should operate at very high frequencies.

The first evaporated electronic component to show a negative resistance, the tunneltron was made by evaporating an aluminum strip into a glass substrate, oxidizing it in air to form a thin surface layer of dielectric aluminum oxide, and then evaporating a thin cross strip of lead on top of the aluminum oxide. The observed negative resistance effect stems from the ability of electrons to pierce or "tunnel" through extremely thin layers about a millionth of an inch thick of material that is normally considered insulating. Observation of this tunneling current, as it depended on the voltage applied across the experimental sandwich, revealed a region of negative resistance, provided the two metals were maintained in a superconductive state.

The cryotron and tunneltron complement each other and both are expected to play important roles in low temperature electronics. An external sufficiently-strong magnetic field lowers the temperature at which matter becomes superconductive. This principle is used in the cryotron and is one means that can be used for controlling the tunneltron.

Behavior of the tunneltron is similar in many ways to the behavior of tunnel diodes. However, devices based on the new discovery promise advantages over tunnel diodes. Chief among these advantages are: the ability to control negative resistance and hence the operation of the tunneltron by applying a magnetic field; extreme ease of manufacture of the tunneltron which offers great flexibility to the designer since the metal-dielectric-metal sandwiches are made by standard vacuum evaporation techniques.

ADL scientists have interpreted the negative resistance behavior in terms of the modern theory of superconductivity proposed by J. Bardeen, L. N. Cooper and J. R. Schrieffer of the University of Illinois in 1957. Among other things, this theory predicts that the superconductive state is associated with a change in the energy of conduction electrons in metals. Certain energies which are permitted to the conduction electrons when a metal is normal are forbidden to it when the metal becomes superconducting; that is, an energy gap exists in a superconductor. Previously, only extremely complicated and lengthy experiments have been used to explore the existence of the predicted energy gap. The present discovery gives a direct and very simple means of measuring the gap. ADL scientists expect to apply their technique to help solve remaining questions about the behavior of superconductors. • • •



"INDEX OF RELIABILITY" . . . Mean Operating Time Between Failures.

Reliability and Maintainability are always important — and most often very critical factors. Their definitions invariably involve "time". Some military specifications use "mean operating time between independent failures" as the index of reliability and call for the incorporation of elapsed time indicators into the operating equipment. Replacing critical components before they reach the limit of rated life contributes greatly to peak operating efficiency and reliability.

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DIGITAL VOLTMETERS

Digital voltmeters are indicators which provide a digital read-out rather than a pointer indication of measured voltage. Their principal advantages lie in the ease with which they may be read, their relatively high accuracy and the availability of a coded output which may be applied to printing equipment for permanent recording. Their principal disadvantages are the general limitations of devices based upon sampling techniques, and the relative complexity of this type of equipment in comparison with ordinary d'Arsonval type meters. Table 1 lists application and advantages of digital voltmeters.

The digital voltmeter is in reality an analog-digital converter, sometimes referred to as a voltage-digital encoder. It is distinguished from the general encoder by the presence of a visual read-out device, and by its compact packaging to suit applications as a voltmeter. Occasionally the voltmeter has no direct read-out and merely provides the digital indication through a common piece of auxiliary equipment such as an electronic counter. In other instances the voltmeter function may be inherently contained in a complex piece of digital apparatus used in conjunction with other digital equipment, in which cases output devices such as tape recorders or printers are employed as auxiliary apparatus.

A good deal of the background necessary to the understanding of the digital voltmeter has been covered in Components Digest No. 7, Part 2 of July 1959 which describes voltage-digital encoders and their operating principles. Particular emphasis was placed on accuracy in high speed systems where significant variation occurs in the analog input during the sampling interval. In this Digest we will review the more important points with particular emphasis on their application to digital voltmeters.

As in Components Digest No. 7, appreciable reference has been made to "Notes on Analog-Digital Conversion Techniques", edited by Alfred K. Susskind of the Massachusetts Institute of Technology. This excellent text cannot be recommended too highly as a well written presentation of the fundamental principles of this increasingly important subject. The book covers also analog-digital shaft position encoders.

SAMPLING FREQUENCY

An understanding of sampling frequency is basic for the intelligent application of voltage-digital encoders. The Sampling Theorem provides the fundamental basis for this conversion equipment. "If a signal f(t) (the input voltage) is sampled at intervals of T, corresponding to the sampling rate 1/T, the frequency components greater than π/τ radians per second cannot be distinguished from frequencies from 0 to π/τ radians per second." Another way of wording the above theorem is as follows: "If the signal f(t) be-

TABLE I

Applications and Advantages of Digital Voltmeters-Ratiometers-Ohmmeters and Input Scanners

(Note: Each of the following features is not found in all digital voltmeters).

1. Output display in easily read numerical form.
2. Automatic scale changing.
3. Automatic polarity indication.
4. Burnout proof operation.
5. Operate automatic data recorders directly.
6. Directly applicable as components of automatic test systems.
7. Applicable to general and specialized measurement problem.
8. Serve as part of complex automatic data logging systems.
9. Exceptionally adaptable to calibration of measuring instruments such as voltmeters and recorders, plotters, etc.
10. Adaptable to calibration of potentiometers, voltage dividers, and similar transducers.
11. Useful in analog computer work.
12. Ideal for amplifier, power supply and regulator testing, particularly with precision equipment.

$F(\omega)$ when subject to Fouries analysis, and if $F(\omega) = 0$ for $|\omega| \geq \pi/T$, then $f(t)$ may be completely recovered from $f^*(t)$ where $f^*(t)$ is $f(t)$ sampled at the rate $1/T$." The statement that $f(t)$ can be recovered from $f^*(t)$ means that nothing is lost by sampling $f(t)$.

The Sampling Theorem is often paraphrased by saying "It is necessary to take more than two points per cycle of the highest significant frequency component in a signal in order to recover that signal." This statement is true, since the critical frequency π/τ has the period 2T. The importance of the sampling theorem is basic if the digital encoder input is a fairly rapidly changing signal.

The Sampling Theorem is *misphrased* by saying in effect that it is necessary to take more than two points per cycle of the highest frequency of interest in a particular application. This statement is wrong, since high frequencies are definitely passed by low frequency sampling, and the high frequency components result in false values of the low frequencies. If high frequencies are present in a function whose low frequencies are to be analyzed, then either a high sampling rate must be used or the function must be filtered to cut out the high frequencies before the sampling operation. In general, for accurate recovery of information in those systems where the frequency components of the input signal taper off in definite fashion, sampling may be carried out at 5 to 10 times the highest significant frequency.

In effect, the Sampling Theorem is of importance primarily in digital systems where recovery of the information originally contained in the input analog signal is of importance. In digital voltmeter applications, the sampling rate must be related to the accuracy of the instantaneous readout with respect to a varying input analog signal. Here naturally the sampling rate must be much more rapid such that any change in input signal during the sampling interval is within the required limits of accuracy of the measurement. Expressed differently, precision of a digital voltmeter is to the nearest least significant digit when a uniformly changing analog input signal results in consecutive changing output readings in the last digit at each sampling. A more rapid rate of change of input signal results in inaccuracies during the sampling interval.

The key point is that regardless of the number of digits in the output indication, there is a definite upper limit to the accuracy of reading a changing input signal depending on the maximum change in signal amplitude during the sampling interval.

BASIC CONVERTER TYPES

In considering the band-width of a converter it is important to consider whether it is a *free-running type*, or a *sampling type*. In both of these types, with the exception of units that use analog measuring techniques and some that use voltage-to-frequency conversion methods, known increments of current are switched into a ladder network which sums voltage and adds to or subtracts current increments until the network output matches the input voltage. In the free running type the current switches are controlled by the bits in an accumulating register. A least count is added to or subtracted from the register, depending on whether the ladder network output is greater or less than the input, at equal intervals of time until the register counts to a value corresponding to the input voltage. The accumulator then oscillates within plus or minus one least count of the input value. The maximum voltage change that the converter can follow is the voltage change produced by the least significant digit divided by the clock period between successive additions. The dynamic response can be improved by sensing whether the comparator is out of balance by more than one voltage increment and when it is causing the bit to add in the next to least significant position. In this way the converter follows twice as rapid a voltage change but to one-half accuracy.

A sampling type electronic converter starts from zero and switches successively from the most significant bit to the least, each time comparing the input to the ladder output. In this way the converter establishes a number which was equal to the input voltage at some time during the sampling interval. The value is held until the converter is commanded to sample again. By making the interval short, input changes during sampling are small.

A variation of this converter employs a sample and hold circuit to clamp the input so that it is constant during conversion. The problems inherent in making a fast sample and hold circuit are nearly as great as in producing a fast converter; however, sample and hold devices can improve the accuracy of this type converter by at least a factor of 10 under certain operating conditions.

Pulse width converters (a particularly important variety of the sampling type) first transform the analog voltage into a pulse width duration proportional to the analog voltage. The pulse duration then gates a string of pulses into a counter where they are counted to arrive at the digital value of the analog voltage. Even with high pulse rates (2 or 3 megacycles) the time required to count to 3 decimal digit accuracy (400 microseconds) is longer than for other electronic analog converters.

CONVERTER BANDWIDTH

The highest frequency a free-running converter can follow is that with a maximum slope of one least count in the sampling interval. Example: If the bit setting time is 4 microseconds and the converter has a 10-bit register, the maximum slope would be one least count (2×10^{-10}) divided by the time to set the bit (4×10^{-6}) and this in turn must equal the maximum slope $2\pi f_{max}$ of the sine wave of maximum frequency. So that, $F_{max} = 2^{-10}/4(10^{-6}) = 34$ cycles per second$/2\pi$

The sampling converter must sample the voltage before it has changed appreciably. Sampling takes a finite length of time. It is the speed of conversion, the time required to set the described number of bits, that determines the converter bandwidth and not the number of sampling operations that can be performed in a given time. Most converters recover very rapidly so that data can be sampled at a very high rate.

To obtain appreciable accuracy from any of the samples, the input must be of quite low frequency content so that the additional samples that could be taken would be redundant and of little value.

The above brief description and analysis indicates that an extraordinarily high sampling rate is necessary to provide good accuracy in voltage-to-digital encoders. Bandwidths are surprisingly low, considering that conversion intervals are measured in microseconds. This subject is examined in considerably greater detail in Components Digest 7, Part II, where a more rigorous mathematical discussion relating conversion rates to accuracy is presented. For our purposes here let it be sufficient to be aware of these points when digital voltmeters are used to provide digital information for data handling as well as for visual readout.

For the moment consider here the use of a digital voltmeter for monitoring to a high degree of accuracy a relatively constant dc voltage. It would be well to assume that some filtering will "protect" the digital instrument from voltage pulses or high frequency transients whose effect on the output may be considerable, depending on timing, and the type of instrument being used.

DIGITAL VOLTMETER SELECTION FACTORS

Table II remarks generally on the factors of importance pertaining to the performance of analog-voltage-to-digi-

tal conversion equipment. Since from the user's point of view the primary requirement is accuracy, we may profitably spend some time considering factors affecting accuracy.

The above discussions point up the importance of sampling rate with respect to accuracy where the input signal is changing. Bernard Gordon of Epsco has studied this problem in evaluating the extremely high sampling rate of equipment manufactured by his company. His findings are summarized in Components Digest No. 7. He reenforces the previous arguments for high sampling rates by pointing out that to digitalize a 100-cycle sine wave to 0.05 percent peak error would require that approximately 600,000 data conversions be made per second.

Considering absolute accuracy limitations further, even under static (input unvarying) conditions, one part in 10,000 seems to represent a practical limit for the calibration of secondary standard equipment. This figure takes into account the use of precision components throughout, and allowance for their original inaccuracies, the effects of aging and the temperature variation. Solid state components such as diodes and transistors exhibit definite changes in characteristics over long periods of time. Zener diode references may exhibit changes of as much as 0.03%/oF temperature change.

There are two fundamental sources of error related to the generation of the internal voltages used for comparison. The voltages generated are fractions of some full scale value and both the fractions and the full scale value itself are subject to error. Errors in the full scale value result in progressively smaller errors for each of the fractional values of full scale. Errors in the individual fractions are uniformly distributed. These two sources of error may be cumulative.

A last source of inaccuracy may be described as zero shift or offset. Mathematically this is equivalent to an addition (or subtraction) of a constant value to all readings taken.

While absolute accuracy as referenced to the International volt may not be a prime requirement, it must be recognized that even relative accuracy may change with time and temperature and must be rechecked from time to time if accuracy is to be maintained.

TABLE II

Characteristics of Conversion Equipment

Form of analog data—Dc voltage, or ac voltage using an additional ac-dc converter.

Range of analog data—Limits between which the analog signal may vary.

Digital code—Decimal, straight binary, cyclic binary, and the 8421 code most frequently used. Decimal code most desirable for data display. The 8421 code is next most desirable for data display. Straight binary code is most suitable as digital computer input.

Number of bits—Precision of conversion equipment is largely determined by the number of bits (binary digits) generated or used.

Quantization Error—The most precise measurement that can be made corresponds to the least significant bit. Error in measurement due to this limited precision is frequently referred to as quantization error.

Accuracy—Refers to the correctness of measurements rather than to their precision. Since some equipment has a tendency to drift, it is often important to speak of accuracy over a given period of time without adjustment or calibration.

Holding characteristics—Holds the input signal constant during the time conversion interval. Requirements for holding and the manner in which it may be accomplished are referred to as the holding characteristics of an encoder.

Number of channels—It may be possible to time share various portions of the converter with a number of inputs or outputs. This process is referred to as multiplexing.

Conversion time—Time record to complete one encoding process.

Conversion rate—Number of conversions which may be accomplished during a unit interval of time. The conversion rate may depend upon certain characteristics, such as the magnitude of the analog input signal.

Total value vs. incremental methods—Some types of conversion equipment generate a complete new value at each conversion, while other types change their output only in small incremental steps.

Feedback and nonfeedback methods—Some types of analog-digital conversion equipment conduct the actual conversion on the output signal rather than on the input. The data obtained in this fashion are compared with the input, and an error signal is developed which readjusts the output to reduce itself to zero. Nonfeedback methods do not involve comparison.

Direct and indirect conversion—Indirect conversion implies that analog data are converted to another analog form before use. In digital voltmeters the analog voltmeter is frequently converted to a frequency, or a time interval.

Precautions must be taken in the installation and operation of such equipment to assure that a properly grounded reference is maintained between the unknown voltage to be measured and the reference supply of the converter. A separate, highly stabilized supply to act as a common reference for both transducer excitation supplies and converter reference supplies is a recommended solution for maximum accuracy.

The dividing network used for the generation of fractional full-scale internal reference voltages must be designed and manufactured with extreme care. In high speed converters where the individual bit decision time is on the order of 2μsec, it will be appreciated that resistors must remain purely resistive at frequencies approaching 1 megacycle. The percentage requirement for accuracy is most acute on the most significant bit or ½ full scale bit and descends by powers of 2 with the smaller fractions of full scale. Thus, if 0.01 percent resistors be used on the ½ full scale bit, the equivalent requirement on the 10th bit is a 5 percent resistor. Strict adherence to these figures may still leave something to be required in the finished unit. It must be remembered that values such as 0.499 are built up as an internal reference voltage by summing as many as 9 fractional voltages in a 10 bit unit. The value of 0.500, however, is made up of only one fractional voltage. Thus, the designer must take care that the cumulative error as a result of summing fractional reference voltages not be allowed to exceed the single error inherent in any one of the fractional voltages. Failure to observe this rule has the interesting result that certain output codes may be nonexistent. Missing codes are a rather severe form of instrument non-linearity.

The considerations discussed lead to certain conclusions regarding practical test programs to establish the accuracy of successive approximation type converters. Tests may consist of:

- *Zero Check*—With the converter input connected to the unknown input signal ground, the digital output should be zero.
- *Absolute Check*—The converter should digitize directly to within ±½ the least significant bit any accurately known voltage source within the range of the instrument.
- *Monotonicity (Linearity)*—As the input signal to the converter is slowly varied from zero to full scale, the operator should observe that each and every possible output code exists over a stable range in proper sequence.
- *High Speed Check*—The converter should be able to accomplish test number 3 at its maximum design rate

APPLICATION NOTES

Digital measuring instruments have extremely good resolution. Noisy input signals should therefore be filtered to obtain a more stable numerical display. Filters of course will slow down the measuring process, since they have a definite time constant. Thomas Nowalinski, Chief Applications Engineer at Non-Linear Systems, points out that noisy signals can be filtered in multichannel data logging systems without decreasing overall speed by permanently connecting a filter to each input channel. Then, while the digital voltmeter is measuring one channel, the other channels will be charging their filters. The relatively high input impedance of dvms simplifies filter design by reducing filter voltage drop. Nowalinski says that there is no such thing as a universal filter, but that a simple LC low-pass filter with a miniature 50 henry choke and a 1 mf capacitor comes close to being generally applicable.

Nowalinski also points out that, in most cases, the metal cabinet of a dvm should be grounded to obtain full accuracy and resolution. In some locations electrical conduit grounding is satisfactory; in others, a good earth ground may be needed. In summary he says that the need for filtering, shielding and grounding increases as the source impedance increases.

Above Ground Operation. In designing a bridge circuit to be connected to a dvm, Nowalinski says that highest accuracy of indication can be assured by using a well-isolated bridge excitation supply and grounding one of the bridge output terminals, instead of grounding one side of the supply. He points out that a floating input provision helps in measuring above-ground potentials. In most dvms, the signal ground can be easily disconnected from the chassis to provide a floating input connection. This type of ground isolation avoids ground loops by permitting a common point other than the dvm chassis to be ground. It also permits fully accurate above-ground measurements where the source impedance to ground is low. Nowalinski also points out that in dvm applications with floating input connections, a capacitor connected between dvm signal ground and chassis ground almost always reduces noise effects.

COMMERCIAL EQUIPMENT

Perhaps the best way to illustrate the principles described above and to point up the practical importance of the various selection factors is to review the characteristics of specific commer-

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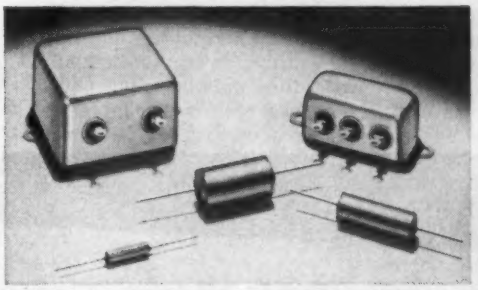

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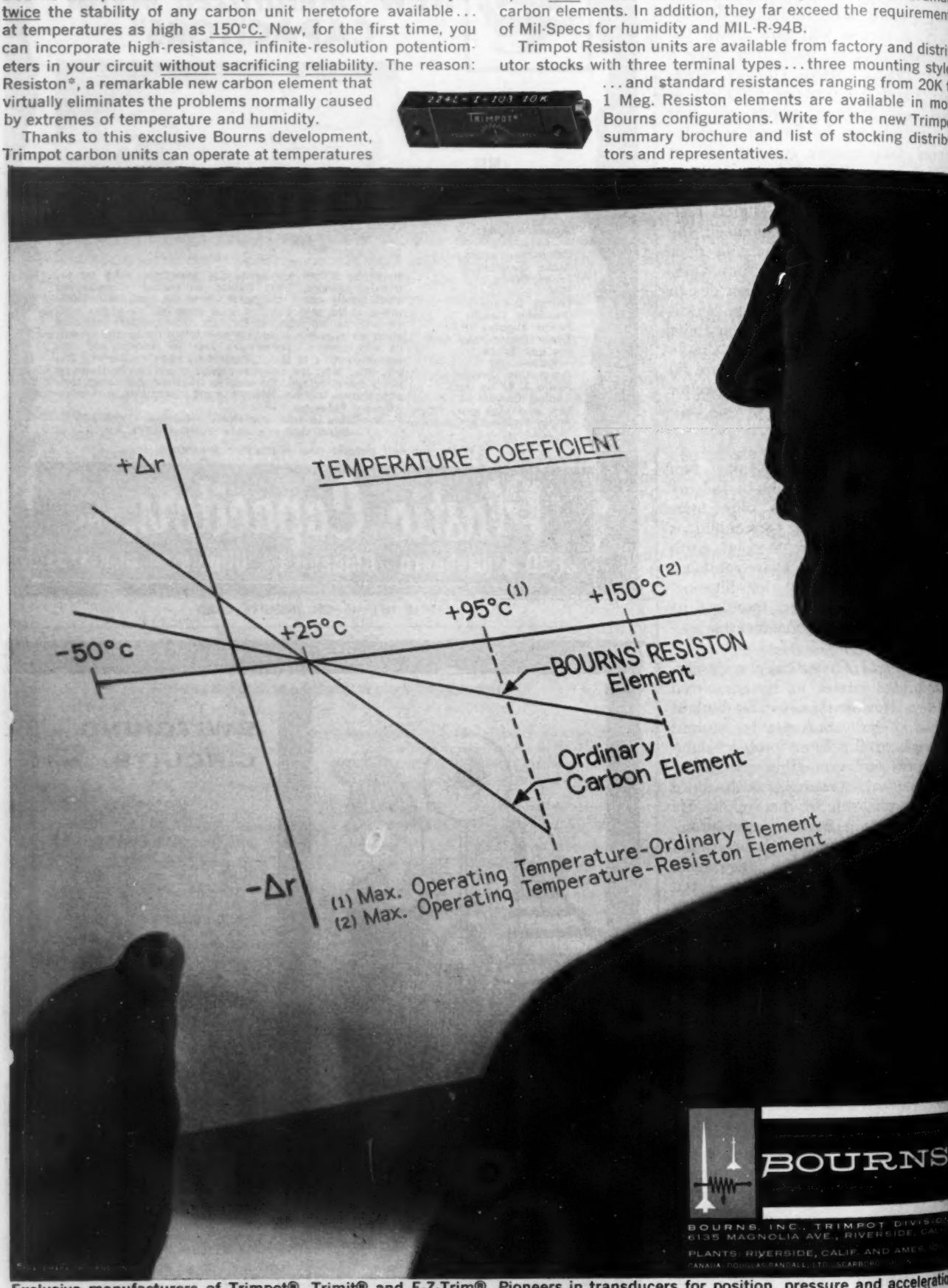

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cial devices produced by the following prominent manufacturers.

Non Linear Systems, Inc. who specialize exclusively in digital voltmeters produce a rather complete line. We will consider some of their products in detail. Their instruments operate by comparing the input voltage with an internally generated balancing voltage. Their operation depends upon a variety of circuit mechanisms:

(1) All electronic type
(2) Mercury-wetted contact relay type
(3) Stepping switch type

These instruments operate on the so-called successive approximation method in which a precision reference voltage is divided into a number of precise increments by a voltage divider using precision wire wound resistors which are switched in and out of the measuring circuits. Starting with the left-most decade (the most significant digit), the instrument's programming circuits sequentially switch each voltage increment into the measuring circuit (where the voltage increments are summed).

Any increment which produces a comparison voltage larger than the unknown input is discarded. The programming circuits operate until each voltage increment has been tried, at which time the instrument is ready for readout or print-out.

These instruments provide 4 or 5 read-out digits with decimal point and polarity sign. Both decimal and binary coded outputs are provided. Sampling rate depends on the basic type—200 readings per second for the all electronic type, 3 complete readings per second for the relay type, and 2.3 seconds maximum per reading for the five digit stepping switch type. For all three types, the only step needed to calibrate the instrument is to periodically (every 30 to 90 days) check the precision reference voltage and adjust it if necessary.

The reference voltage is adjusted by connecting external standard cells (cadmium-mercury Weston cells) to the instrument, and turning a control located inside the instrument until the instrument reads the correct number. The instrument's precision reference voltage is furnished by Zener diodes matched to ±0.001%/C which are mounted in a constant temperature oven stable to ±1/2°C. After many years of experience with many types of precision reference supplies for digital instruments, NLS has standardized upon the Zener diode type reference because its extreme simplicity offers greater reliability, yet the instrument's stability is not in any way compromised. Accuracy in all cases is ±0.01% of full scale on each range.

A major design feature of the electronic units is the extreme stability of the electronic switches used in the potentiometric circuits. These switches are so stable that trim pots are not required to correct for initial and/or eventual imperfections in the switching circuits.

The mercury wetted type instrument depends upon switching by relay contacts rather than by electronic switches. The mercury wetted contact is said to have a life expectancy of 57 years operating continuously at the instrument's highest speed. Programming and logic circuits are transistorized. The mercury relays are used to furnish maximum precision in stability and reliability in the poteniometric circuits. The mercury relays do, however, result in a slower measuring speed than is obtainable in all-electronic instruments. Semiconductors are used in the logic and programming circuits since they do not require switches with such low forward-to-back resistance ratio as do the potentiometric circuits.

The stepping switch type of balance circuit features novel design characteristics. The stepping switches are mounted in oil filled interchangeable plugin container. The oil bath eliminates the need for disassembling the instrument periodically for lubrication and it also extends stepping switch life by providing continuous lubrication to keep friction loads at an absolute minimum throughout the life of the switch. The plug-in interchangeable feature is also valuable in trouble-shooting and maintenance. NLS claims these meters are the only stepping switch instruments that use successive trials logic in which each digit is computed in a programmed procedure starting with the left-most decade and progressing to the right-most decade. Interlocking circuitry prevents any digit from moving once it has been computed, and results in each reading being meaningful, even if the input voltage is varying during the measuring cycle; for example, if the voltage is varying from 3.1962 to 3.2015 during the measuring cycle, the reading displayed will be some number between those two values. Other stepping switch instruments will hunt and produce almost any material value if the voltage is varying during the measuring cycle. The only way to prevent other instruments from hunting is reduce their sensitivity in accordance with the amount of signal variation or signal noise present during each measuring cycle, a procedure which is at least inconvenient in automatic systems. The "no needless nines" logic also measures in the shortest balancing time possible, (balancing time is only 1/3

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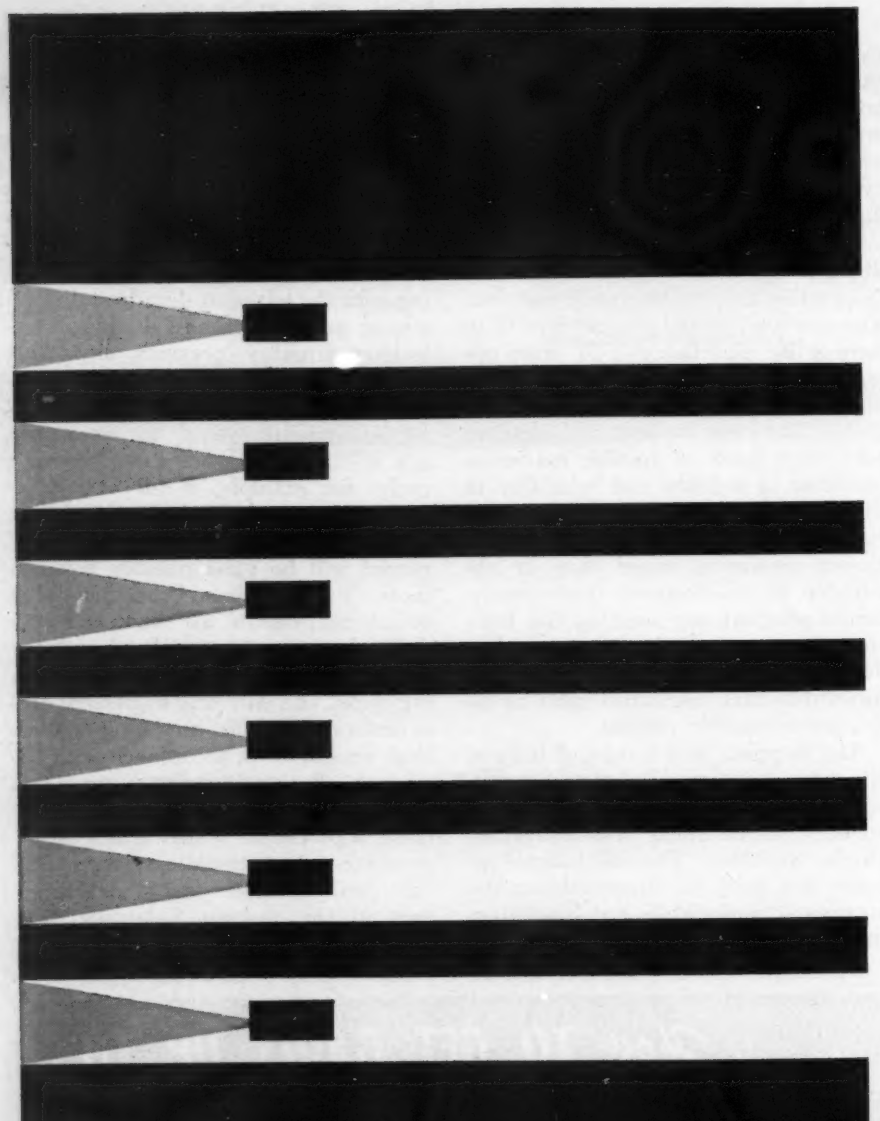

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as long as that of other stepping switch voltmeters). Therefore, the stepping switches in these instruments will last far longer than they would in more conventional circuitry.

According to NLS, stepping switch instruments which use a "tracking" type logic that causes the instrument to continuously track any change in input voltage have the disadvantage that the balancing logic progresses from right to left rather than from left to right; thus, if the voltage changes from 3.182 to 3.282, the two right-most digits must both increase to a value of 9 before the 1 can change to a 2, then, the two right-most digits must cycle through 0 to 9 again several times before the reading 3.282 can be obtained. This type of logic results in needless wear on the stepping switches and it increases measuring time, as well as causing a very serious problem in automatic data logging systems where some signals may be very constant and require accurate measurement, and other signals may be varying during the measuring cycle.

NLS stepping switch voltmeters use transistorized logic which means only 1/2 as many decks on each stepping switch, with a consequent increase in stepping switch life brought on by a decrease in stepping switch friction and inertia load.

NLS offers a low cost dry stepping switch digital voltmeter for industrial applications. In these units switching of the precision resistors in the potentiometric circuits and also the logic operations are performed by stepping switches. Being dry, the stepping switches must be periodically lubricated. They utilize the more conventional "tracking" digital logic which, as explained above, causes the instrument to hunt whenever the input voltage varies, preventing the instrument from reaching a balanced condition unless the instrument's comparison amplifier gain is sufficiently decreased so that the instrument cannot detect the amount of variation that is occurring. The gain is easily adjusted when such instruments are used for visual reading purposes, but this form of logic does present a problem whenever such instruments are used in automatic data logging or automatic testing systems. The manufacturer states that these are the lowest price full four digit stepping switch digital voltmeters available anywhere, their low cost being due to high volume production and use of a thoroughly proven, easy-

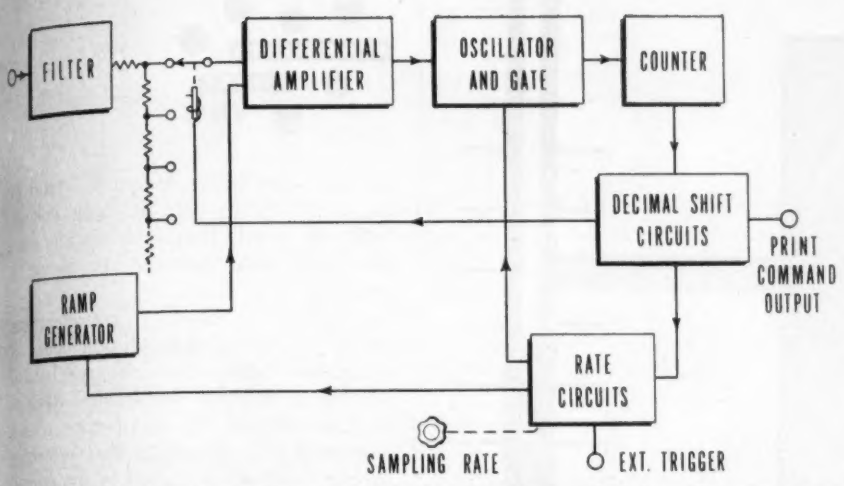


Fig 1 Basic circuit arrangement of Hewlett Packard voltmeter. Use of ramp-type design offers significant advantages for general-purpose instrument.

produce design.

AC measurements can be made with a dc voltmeter by use of NLS converters in which semiconductor diodes convert the unknown ac input to pulsating dc, which is filtered to obtain a pure dc voltage proportional to the average value of the ac wave form. A high gain feedback linearizes and stabilizes the rectification characteristics of the diodes. In other models, an internal precise dc voltage is compared with the unknown ac voltage which is passed through a square law detector to give true rms values. In a unit which basically senses average value in an application requiring true rms readings, waveform distortion will cause apparent errors in the measured data. The error is a function of the form factor relating true rms and average values for the particular waveform being measured. A true rms unit, on the other hand, gives an apparent error if the application demands average value readings. The choice should be based upon the type of device being evaluated. A true rms ac voltmeter should be used where the device being evaluated is basically sensitive to the rms value, and where sine wave distortion is great enough to make a significant difference between the true rms value and the value read by an average sensitive ac digital voltmeter.

Frequency range is 30 cps to 10 kc at 0.1% accuracy, although higher frequencies can be read with reduced accuracy.

Non Linear Systems, Inc. predicts for the future: As in almost all electronic instruments, reliability, ease of service, versatility and cost will be improved, no matter how advanced the "state of the art". Improvements now under study include simplified high speed instruments, faster ac instruments, more versatile control provisions, wider measuring range, additional input and output accessories, low cost instruments with the plug-in features of higher cost instruments, instruments that operate under stringent environmental conditions.

Hewlett-Packard describes a digital dc voltmeter that measures positive or negative dc voltages within the range from 1 millivolt to 999 volts and displays the measured value, including polarity and decimal point, in large illuminated digits. The instrument permits automatic logging of measurements, since it is designed to directly drive a high-speed digital recorder to produce printed records of measurements. Functional coding, polarity and decimal location can all be included in the printed record.

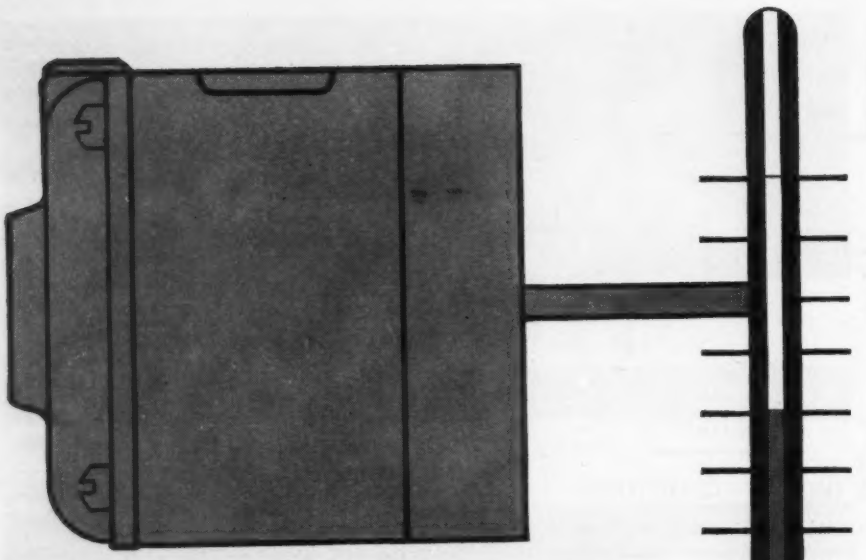
Electrically, the new voltmeter has a calibration accuracy of ±0.2%. It has a high input impedance of 11 megohms, and its input circuit is floating so that it can measure voltage sources that are up to ±500 volts off ground. Overload protection is also provided. Hum rejection is 50 db or more with the result that hum peaks as large as 1/3 of the dc in a circuit being measured cause an effect of only ±1 count in the least place of the readout. The instrument includes a self-check feature such that accuracy can be tested at any time by pushing a panel switch. The instrument has a sampling rate adjustable from 5 measurements per second to 1 per 5 seconds, externally electrically or manually controllable.

Design Approach. The new voltmeter uses the circuit shown in Fig 1 in which an accurate, linearly-rising voltage ramp is generated and compared with the attenuated dc to be measured. Coincident with the start of the ramp, a gate on a clock oscillator is opened and kept open for the time interval needed for the ramp to become equal to the voltage being measured, at which moment the gate is closed. During this interval the number of clock pulses that have been gated out are counted by an electronic counter circuit. By suitably relating the slope of the ramp to the clock frequency (the time needed for the ramp to increase 1 voltage unit is made equal to 1 oscillator cycle period), the counter display is made to equal the measured voltage. Suitable sensing circuitry in the counter causes the input attenuator to be switched automatically to the optimum position and also automatically positions the decimal point in the counter display. The display system itself consists of 1-inch nixie tubes, giving a large, bright, easily-read display using industry-standard components.

After the external voltage has been measured the circuit continues automatically to re-measure the external voltage at a repetition rate determined by the setting of a panel control. The operator, however, continues to see an uninterrupted display which changes only when the measured voltage changes. The measuring cycle takes 200 milliseconds so that up to 5 repetitive measurements per second can be made, except that on the initial measurement, where it is possible that the circuit may have to scan all its ranges to find the optimum, the measurement can require up to 2 seconds. Successive readings of the same voltage can then occur at 5 per second.

Ramp Design Considerations. For a general-purpose type of dc voltmeter, the ramp type circuit outlined above offers a number of advantages. For one thing it results in an economical design commensurate with the character of a general-purpose instrument. At the same time it gives a performance that is about an order of magnitude higher in nearly all respects than that of the conventional vacuum-tube dc voltmeter. Accuracy, for example, is 0.2% as compared with a maximum of 2% for a conventional instrument, while resolution is 0.1% compared with 1% of full scale for an instrument using a D'Arsonval type display. This higher performance, of course, is combined with automatic operation, a digital display, and the potential for automatic data logging.

From the standpoint of possible automatic-type circuits, too, the ramp circuit offers advantages for general-purpose work. To the user one of the most apparent is that the ramp-type instrument always produces a measurement for voltages within its range. Where a slightly unstable voltage is being measured, for example, the ramp-type circuit measures the voltage at a discrete point in time and displays the value measured. Subsequent measurements will then show the amount of instability present in the voltage. Continuous-comparison type arrangements,



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To solve this problem, engineers from both the instrument company and from Holtzer-Cabot cooperated in the development of a motor with increased radiation area, plus reduced power input. This resulted in a motor temperature rise of only 20° C. as compared with 35° C. in the motors formerly used.

To provide positive lubrication, grease reservoirs were provided outside the bearing and a long-life stable grease suitable for high temperature was selected.

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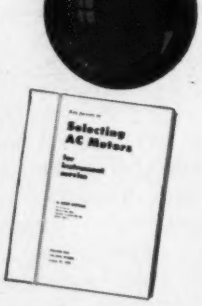

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on the other hand, frequently tend to be confused by an unstable voltage with the result that such circuits continuously hunt without producing a reading.

Finally, reliability considerations favor the ramp-type circuit since it minimizes the use of mechanical switching or other mechanical devices. In this respect the ramp-type circuit possesses the advantage that switching mechanisms are not used in the normal measurement, being required only for range-changing purposes.

Accuracy. In addition to other factors, one of the advantages of the Hewlett-Packard voltmeter is that its accuracy ($\pm 0.2\%$ ± 1 count) applies to the reading displayed, rather than to the full scale value of the range on which the measurement is obtained, as in conventional instruments.

As may be expected from a 0.2% accuracy rating, the chief uncertainty is introduced by the high-impedance attenuator at the voltmeter input. The attenuator used has an accuracy rating of $\pm 0.1\%$, which constitutes 50% of the overall measurement tolerance.

The second main component of measurement tolerance is concerned with the internal voltage ramp. Ideally, the ramp should be linear, but practical methods for generating ramps result in some non-linearity (within 0.05% of an ideal rise at all points—Fig 2).

Dymec, a Division of Hewlett-Packard Co. manufactures a digital voltmeter which is essentially a voltage to frequency converter. This device together with a counter forms an average-reading digital voltmeter. The

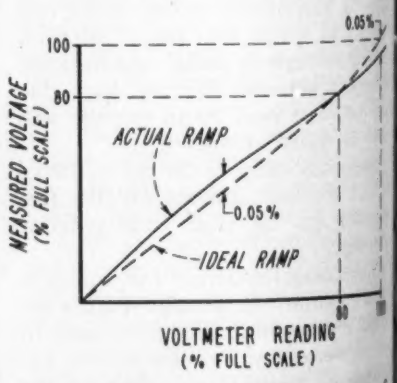
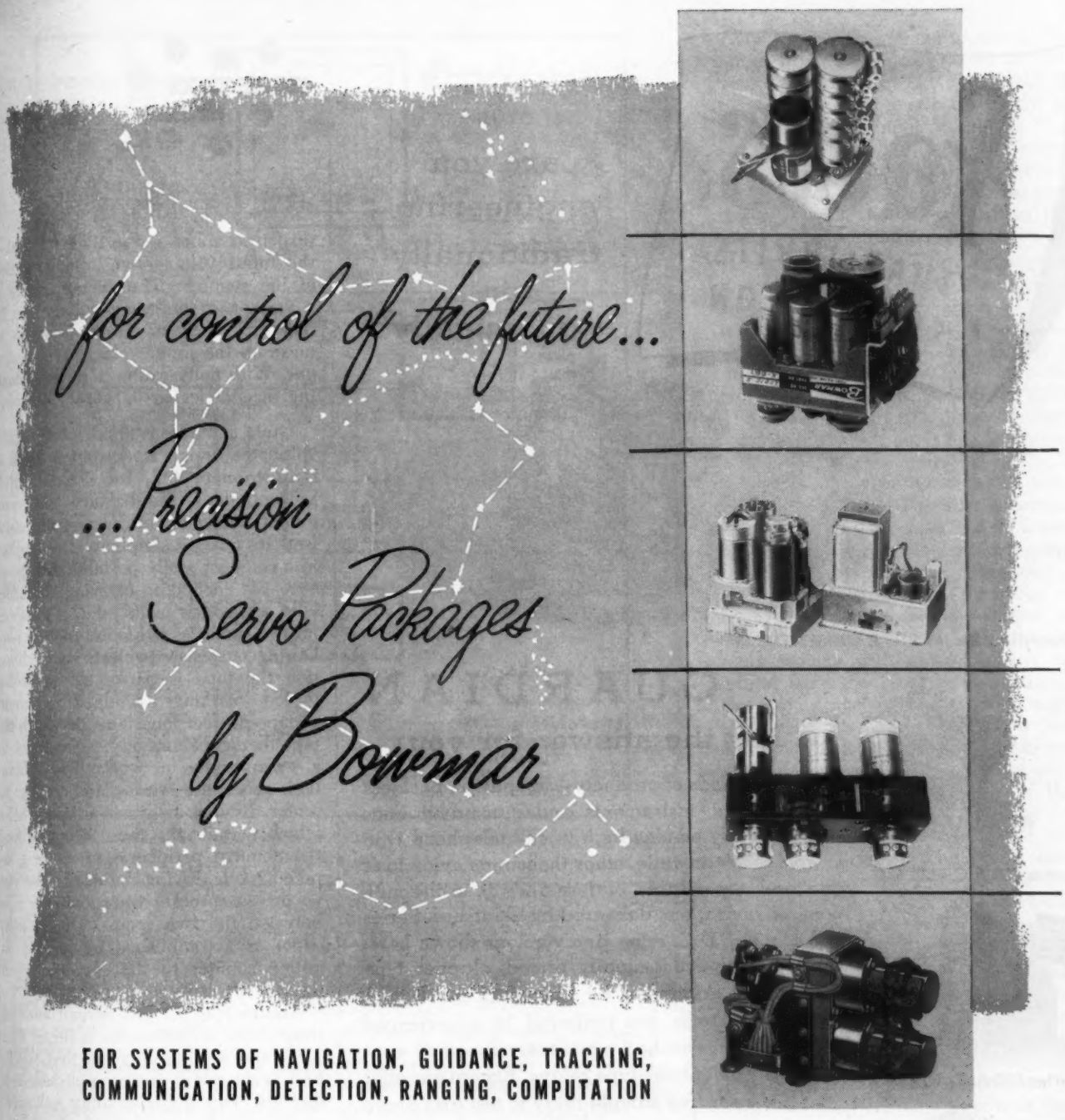


Fig 2 Diagram illustrating nature of non-linearity of internal ramp voltage used for comparison purposes with non-linearity shown on exaggerated scale for clarity. Voltmeter calibration check described in text maintains ramp cross-over at 80% point, as illustrated.



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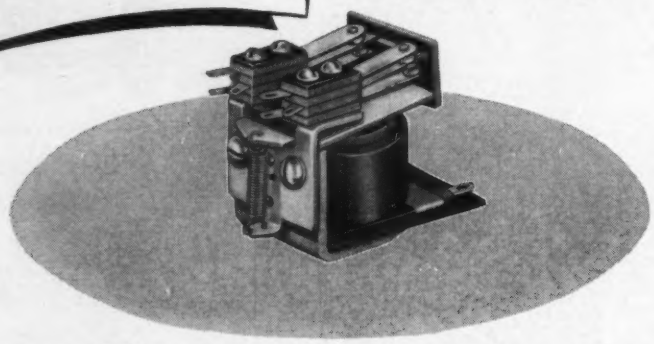

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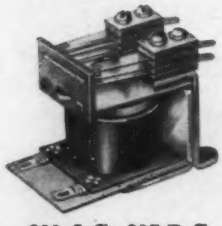

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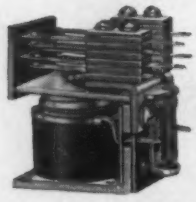

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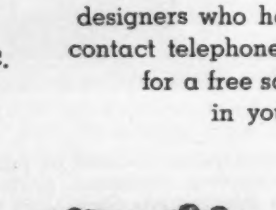

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displayed count is the time integral of the input voltage over the gate time of the counter. The average value of a varying or pulsating voltage can be measured and the effects of ripple or noise on the input voltage is averaged out. With daily calibration and balancing, accuracies to 0.04% are obtained.

Quite a different approach to digital voltmeter design is described by **B & H Instrument Co., Inc.** Their unit is a continuous null-balance slide-wire potentiometer driven by a sevomechanism. Its relative simplicity has resulted in a compact easily portable design.

A 144 inch tape carrying the slide-wire embedded in its edge is mounted on two spools as is motion picture film. During automated electronic calibration the tape is perforated according to code markings contained on a master tape 60 feet long, against which the tape being calibrated is compared in a servo bridge network. The calibration procedure varies the center to center distance between adjacent holes which permits the tape to lag or lead the nominal peripheral travel of a tapered tooth driving sprocket. The servo driven sprocket transports the tape between the two spools. Digital indication is accomplished by gearing an in-line counter to the sprocket wheel drive shaft.

Accuracy is 0.1% in normal ambient temperatures. Calibration is better than 0.05% and resolution better than 0.02%. Full scale travel is accomplished in 8 seconds. This digital-readout voltmeter meets military specifications for vibration, radio noise, altitude and shock. Temperature range is −55 to +70C.

B. & H. Instrument Co., Inc. has applied this slide-wire principle to a whole line of measuring instruments for measuring frequency, rpm, temperature, weight, and other variables.

An analog servo balanced digital unit is also maketed by **Physical Sciences Corp.**, an affiliate of Packard-Bell Electronics. Fig. 3 shows the block diagram of the design. Table III summarizes the specifications. Note particularly the sensitivity of this instrument designed to measure very small voltages to a high degree of accuracy.

Systron Corporation offers a voltage to time converter which may be used with an electronic counter as a high speed digital voltmeter. The Model

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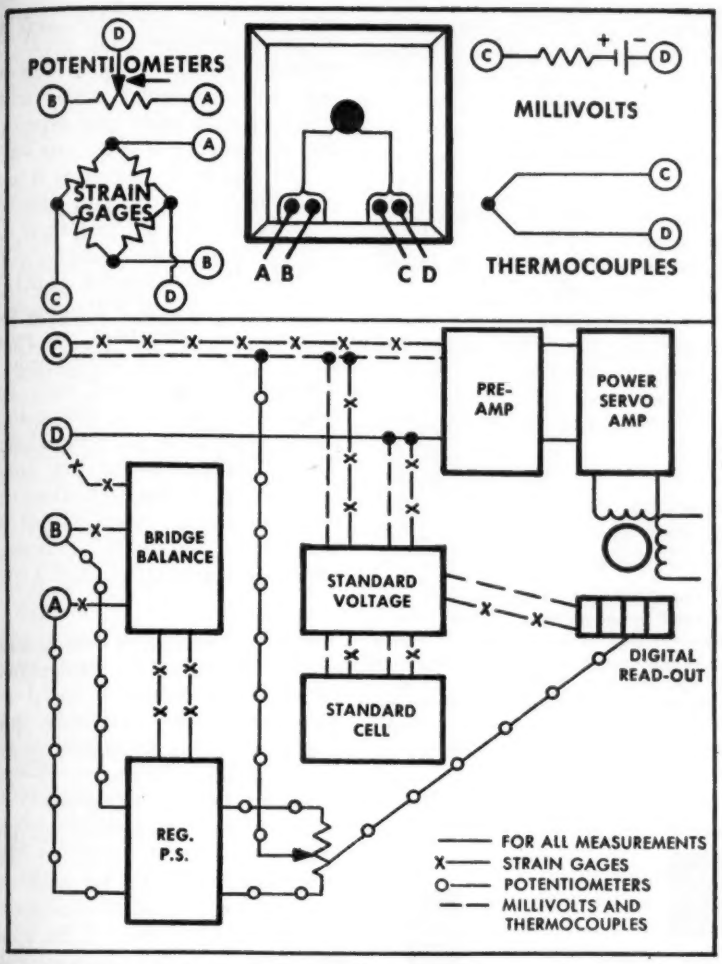

Fig 3 Block diagram of servo balanced digital voltmeter by Physical Sciences Corporation.

TABLE III

Detailed Specifications on Unit by Physical Sciences Corp.

Input: Bonded or unbonded full bridges, thermocouples, Resistance temperature thermometers, low level dc voltages, and potentiometers.

Input Impedance: Operates on null-balancing principal; impedance is essentially infinite in balance condition.

Output: Servo positioned digital indicator. One thousand (1000) counts for full scale. (Digitizer system available for automatic data recording).

Minimum Common Mode Rejection: 180 db at dc, 140 db at 60 cps with input guard returned to common mode source and an unbalance of up to six hundred (600) ohms in series with either input lead. Rejection ratio normally is adequate to operate with partially shorted transducer in average service.

Millivolt Ranges: ±1, ±10 and ±100.

Ratio Range: 100%.

Accuracy: ±0.1% on all ranges.

Resolution: 1 mv full scale—1 microvolt
10 mv full scale—10 microvolts
100 mv full scale—100 microvolts
Ratio —0.1%

Polarity: Selection permits up scale reading of either positive or negative input signals.

Response: In standard models, all ranges except one (1) mv, eight (8) seconds for zero to one thousand (1000) counts. Response time to four (4) seconds available).

Zero Drift:
Short Term: Less than ±0.1% on any range for an eight (8) hour period.
Long Term: ±2 microvolts in a twenty-four (24) hour period.

Calibration: An internal Eppley Standard Cell is provided for standardization of slide wire voltage.

Compensation Voltage Balance: When used as a portable secondary standard of voltage measurement, ±0.1% accuracy of the absolute full scale value can be maintained by referring to a precision laboratory standard of voltage, such as K_2 or K_3 Leeds and Northrup Potentiometers.

Power: Requires 105-125 volts, 60 cycles.

Transducer Power: A ±0.1% regulated power supply to furnish one to ten volts dc is self contained.

Size: Portable—10½" x 10" x 16½"
Rack Mount—12" x 19" x 14"

Weight: Thirty-five (35) pounds.

1230 accepts dc voltage inputs in the range from ±3 microvolts to ±1000 volts and provides an output of 2 pulses separated in time directly in proportion to the input dc voltage. This system not only has digital voltmeter accuracy, but can make frequency, time period, ratio, and phase measurements as well, in each case using the same basic counting equipment.

In the operation of this equipment, the input voltage passes through a chopper stabilized amplifier to achieve a fixed sensitivity. A pair of summing resistors add the amplifier output to a ± reference ramp voltage which increases linearity with respect to time. The sum is applied to a diode discriminator which puts out an S curved waveform with the inflection in the S occurring at the instant the two voltages are equal and opposite. A second derivative amplifier puts out a waveform which crosses the zero axis going positive at this inflection, triggering a blocking oscillator when the ramp is equal and opposite to the dc input. A second identical channel compares the ramp voltage with ground, giving an output from the blocking oscillator at the instant the ramp passes through zero. The resulting two pulses are separated by a time proportional to the input voltage and the sign of the voltage is indicated by the order of the pulses. A gate opens for this time interval passing a crystal controlled frequency to beam-switching-tube decades. The decades then register the input voltage directly in volts and millivolts. The decades are reset to zero before the following voltage sweep repeats the cycle.

Systron provides the complete digital voltmeter including visual readout based upon the above principles.

The dc unit is a 4-digit, all-electronic digital voltmeter with a resolution of ±.0001 volts (±3 microvolts with special option) and sampling rates to 25 per second even with continuously changing input signals, delivering an accuracy of ±0.05%. A crystal controlled 1 megacycle frequency is counted on four 50,000-hr rated-life beam-switching decades for the precise time interval proportional to the positive or negative input voltage. (10,000 counts equals 10 milliseconds equals full scale voltage.) Superior linearity in the ramp, negligible zero and slope drift and 1 microsecond resolution in the pulse generating discriminators are secured in this time modulation system through the use of advanced techniques.

For ac measurements the Systron Model 1240 provides a precision dc output directly proportional to the *true rms* of an applied ac voltage regardless of the waveform of the input. Labora-

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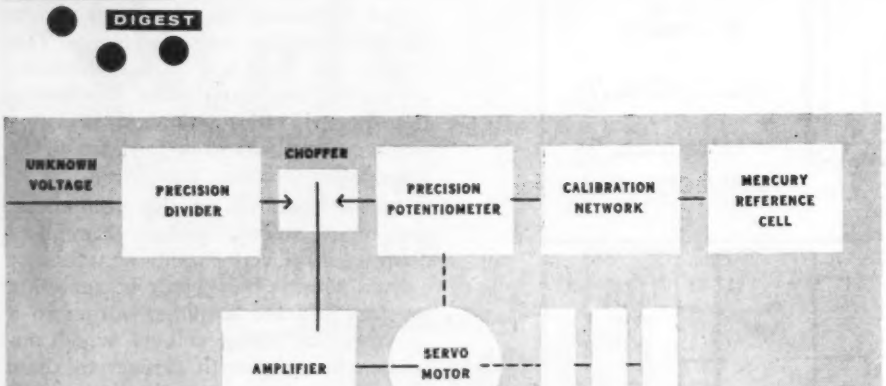

OPERATING PRINCIPLES

A precision resistor division of the unknown voltage is compared by means of a chopper with a precision potentiometer division of the calibrated output of a reference mercury cell. The amplified 60-cycle voltage difference is applied to the servo motor, which drives the precision potentiometer and the digital indicator. When the two voltages balance, the unknown voltage is read directly on the digital indicator.

Fig 4 Digital voltmeter operating principles. Courtesy Hycon Molectronics.

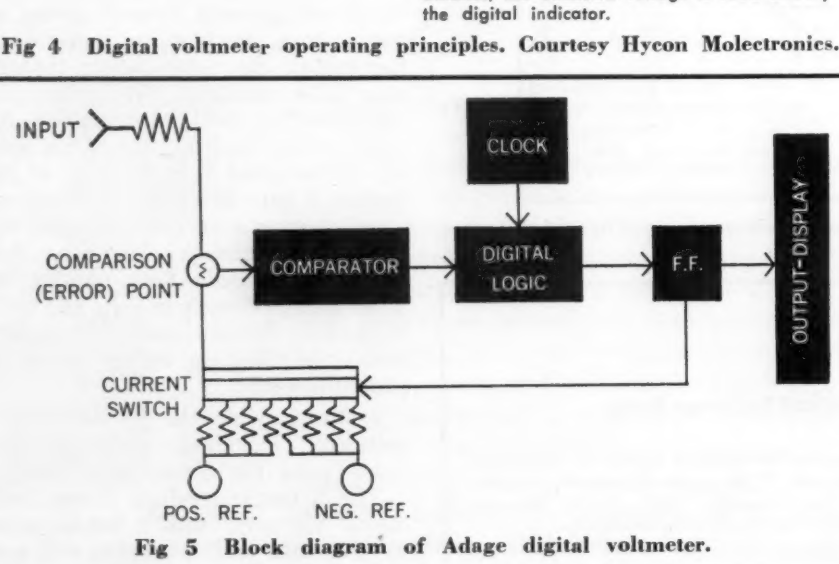

Fig 5 Block diagram of Adage digital voltmeter.

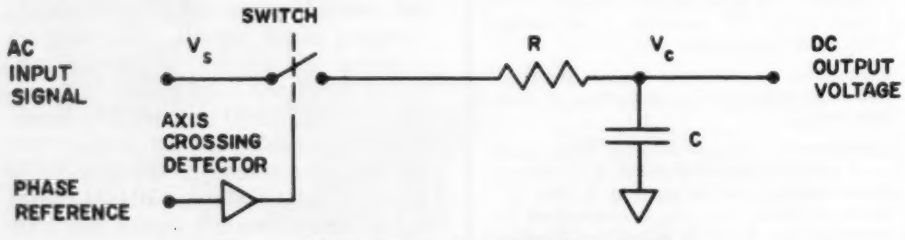

Fig 6 Adage ac to dc conversion circuit.

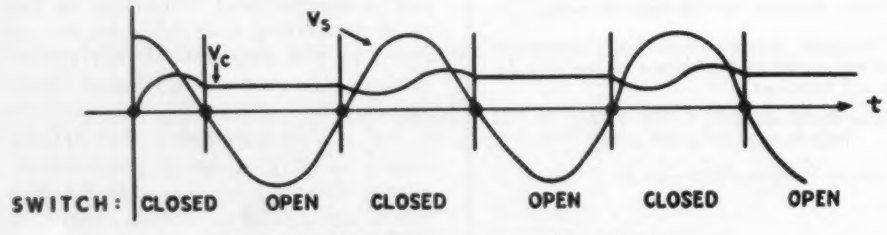

Fig 7 Waveforms in conversion circuit.

tory standard accuracy readings are achieved without the usual sluggish response, excessive signal current loading, and non-linear scales which are common with most heat type detectors and dynamometer type rms meters.

The rms to dc converter is useful for production testing and development work because of its long-term stability, high accuracy, and simplicity of controls. Full scale ranges of 0.1, 0.3, 1, 3, 10, 30, 100 and 300 are selected by one control providing an output of either 10 or 3 volts dc full scale. Other controls include a full scale and low range adjustment for setting to an absolute value from an external standard. The dc output has a low impedance for driving a meter, analog recorder, data processing system, or can be combined with a dc digital voltmeter to operate as a precision ac digital voltmeter.

Hycon Electronics Incorporated, recently purchased by Molectronics, offers a digital voltmeter based upon the servomechanism balancing principle. Fig. 4 describes the basic operation in block diagram form.

In measuring dc voltages, the test voltages are attenuated by precision voltage-divider circuits, so that full scale input voltages for each range of measurement cause a maximum of approximately one volt to be applied to one side of a chopper comparator circuit. AC voltages are attenuated by a frequency-compensated divider network, then rectified and filtered before being applied to the comparator. A precision potentiometer applies a portion of the potential from a mercury reference cell to the other side of the chopper comparator.

The chopper compares the test voltage with the potentiometer voltage at a 60-cps rate. Therefore, the comparator output is a 60-cps voltage with an amplitude which depends on the difference between the test and potentiometer voltages. If the two voltages are equal in value, the output of the comparator is zero.

The 60-cps output of the chopper comparator is amplified and used to energize the control winding of a servo motor. The servo motor drives three cylindrical dials through a reduction gear system and also drives the arm of the precision potentiometer.

The potentiometer arm is normally in the position which places it at ground potential with the servo motor at rest and the indicating dials at 000. When a test voltage is applied to the instrument, the servo motor tends to move the potentiometer arm either clockwise or counter-clockwise, depending on the polarity of the input signal and the position of the input selector switch.

If the polarity of the input signal

does not agree with that indicated by the input selector switch, the servo motor tends to turn the indicating dials backwards. Mechanical and electrical stops prevent the dials from moving far enough to damage the mechanism. If the polarity of the input signal agrees with that of the input selector, the motor rotates the indicating dials and the precision potentiometer in the proper direction. Since the input selector switch reverses the polarity of the mercury reference cell, the polarity of the potentiometer arm always agrees with that indicated by the selector switch.

Voltage overloads or inverted polarity are indicated by a red signal lamp.

As the servo motor drives the potentiometer, the amplitude of the voltage applied to the comparator from the potentiometer increases until it equals the amplitude of the test signal at the other side of the comparator. When this occurs, the output of the chopper amplifier drops to zero and the servo motor stops. The indication dials then read the value of the input signal voltage. The decimal point placement and signal polarity are indicated by lamps which illuminate appropriate symbols on the front panel of the instrument. If the test voltage is too high for the scale in use, a limit switch keeps the dials from rotating more than 40 digits beyond 999 and a neon diode limits the voltage input to the comparator to provide electrical overload protection.

Resistance measurements are made by means of a Wheatstone bridge circuit. Voltage for these measurements is supplied by two mercury cells in series. The motor-driver potentiometer is made a part of the bridge circuit so that the bridge is made to balance as the motor drives the potentiometer arm. When the bridge balances and the servo motor stops, the resistance of the external resistor appears on the indicating dials and the scale multiplication factor can be read from the position of the range switch.

Adage Inc. offers a complete line of digital voltmeters as well as considerable additional digital instrumentation. Their trade name "Voldicon" applies to a family of high-speed, all semiconductor, current balancing devices that use digital logic and readout for high-speed precision measurement of analog signals, see Fig 5.

During a Voldicon conversion, the signal input current flows through an input resistor to a comparison point. A comparator senses the polarity of the comparison point and provides an error signal to the digital logic. In response to a sequence of clock pulses, the digital logic connects a series of digitally weighted precision resistors between the comparison point and an internal reference.

At the completion of a conversion, the input current is precisely balanced by the current through the resistors. The total digital value of the balancing current is stored in the flip flops and may be displayed or read out until initiation of the next conversion.

Each conversion is *completely independent* of the preceding conversion and the speed of the process is such that the display looks continuous, allowing you to follow a rapidly changing voltage.

The Adage meters feature very high sampling rates, up to 15 kc on special order. On ac, the meter senses average but reads rms over a frequency range of 50 cps to 1 kc flat to 0.05%. The following description of the Adage circuit for ac to dc conversion is taken from a company application note.

This Adage ac to dc conversion method is implemented with all solid-state precision amplifiers and semiconductor switches. The circuitry used represents a specific departure from the conventional transformer-coupled diode rectifier or ring demodulator techniques. It is essentially an "averaging" technique (normally calibrated to read rms) which provides flexible choice of either self-synchronous or phase sensitive measurement of the ac signal.

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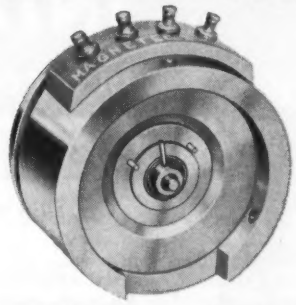

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Re-centering spring torque is not applied until clutch is disengaged. Operational torque is thereby kept to an absolute minimum, making the unit ideal for gyroscope pick-off applications. Dual winding coil construction permits 12 or 24 volt operation, depending on application.

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For complete technical data write for Specification Sheet No. 1509-8A.

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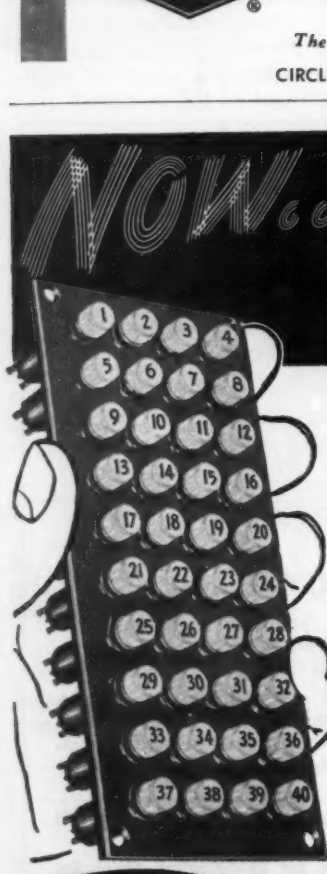

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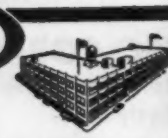

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COMPONENTS DIGEST

Several different standard printed circuit modules are used for ac to dc conversion. These can be combined with any of the Voldicon voltage digitizers to provide instruments capable of a wide variety of ac measurements.

The essential mode of operation is illustrated by the idealized diagram of Fig 6. The input signal is connected through a switch to an RC averaging network. The voltage on the capacitor represents the output of the device. The switch is opened and closed by the output of the axis crossing detector. Input to the axis crossing detector is the phase reference for the measurement. To accomplish self-synchronous measurement, the input signal itself is connected to the phase reference input terminal.

The significant waveforms for self-synchronous ac to dc conversion are shown in Fig 7. The sinusoid V_s, the input signal to be measured, is shown for the case where the input is zero until time $t = 0$, at which time the signal is connected to the input terminal of the device. The switch is operated by the axis crossing detector, whose input is assumed to be connected to the signal waveform. The switch is closed for positive values of the signal voltage, thus connecting the signal waveform to the RC averaging network, and the switch is open when the signal waveform is negative.

When the switch is open, the voltage on the capacitor remains constant since there is no path through which the capacitor can discharge. With the switch closed, the averaging network responds to the input signal, so the voltage on the capacitor "follows" the signal with a simple time constant, RC.

The waveforms in Fig 7 illustrate the consequence of connecting a signal voltage to both signal and phase reference input terminals at time $t = 0$. Charge on the capacitor is initially "0". With the switch closed, voltage V_c on the capacitor increases as long as V_s is less than V_s. When V_s becomes smaller than V_c, the voltage V_c decreases. When the switch opens, the voltage V_c remains constant. After several cycles, V_c arrives at a steady condition where the constant voltage, with the switch open, is the same on successive cycles of the signal waveform. During the half-cycle in which the switch is closed, a ripple voltage is present across the capacitor. During the half-cycle in which the switch is open, the voltage is constant with no

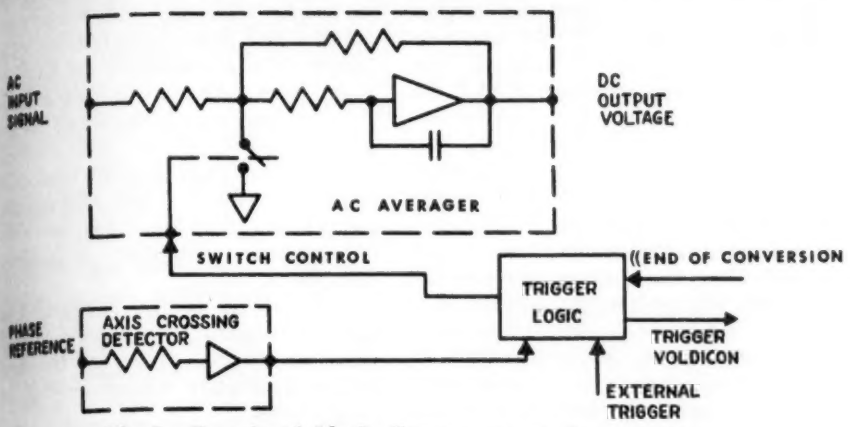


Fig 8 Functional block diagram, ac to dc converter.

ripple present. Subject to certain constraints on the ratio of the RC time constant to the period of the signal waveform, the constant voltage present when the switch is open can be shown to be equal to the average value of the positive half-waves of V_s. Thus, the circuit provides a dc voltage output which is a precise measure of the half-wave average of the applied signal.

It is not necessary that the peak-to-peak ripple, present during the half-wave when the switch is closed, be filtered all the way down to a level equivalent to the precision with which the measurement is being made: i.e., the steady voltage when the switch is open equals the half-wave average to an accuracy of better than .05% of full scale even though the ripple present when the switch is turned on is much larger than .05% of full scale. The averaging result is that the average value can be acquired rapidly, in fact, almost an order of magnitude faster than can be accomplished with conventional rectifying and filtering, where the filter time constant is constrained to be very large in order for the ripple to be filtered down to a peak-to-peak value smaller than the desired precision of the measurement.

With no frequency compensation, response time of the circuit turns out to be equal to 40 cycles of the lowest frequency which is to be measured to an accuracy of .05%. With straightforward frequency compensation, speed of response is improved so that the circuit responds to within .05% of its final value within a time interval equivalent to 15 cycles of the lowest frequency to be measured.

The functional block diagram of Fig 8 corresponds more precisely to the actual physical hardware used to perform ac to dc conversion. A precision dc operational amplifier is included in the ac averaging module to provide voltage gain from the input terminal and also to provide a low output impedance so that current may be drawn from the output terminal even when the switch is open and the output is "holding" a constant value determined by the charge on the storage capacitor.

The trigger logic module is used to insure that voltage to digital conversion occurs only when the ac averaging module is "holding" a constant value. A single channel of ac to dc conversion is thus implemented with three standard 5 x 8 inch printed circuit modules.

When ratio measurements must be made, two channels of ac to dc conversion are required: one for the signal channel and one for the reference channel. If the two channels are to operate from the same phase reference, it is necessary to add to the three modules required for single channel operation only a single extra module, another ac averaging card. The axis crossing detector and trigger logic are used in common to the two channels.

Completely independent operation of two channels requires an ac averager and an axis crossing detector for each of the channels. For this case, the trigger logic module can still generally be shared by the two channels.

The ac averager and the axis crossing detector modules both provide for incorporation of input ranging resistors to accommodate three standard voltage ranges: 1 volt, 10 volts, and 100 volts full scale rms, at 10,000 ohms per volt. Provision for 1000 volts full scale input, in addition to these three ranges, is normally accomplished by an attenuator external to the cards.

Kintel, a Division of Cohu Electronics, Inc., features digital voltmeters designed to conform with MIL-E-4158A. Their model 412 is claimed to be built for use with operational ground support equipment for missile sites. DC voltages are measured with 0.01% ± 1 digit of reading accuracy. AC accuracy is within 0.1% of fullscale.

The initial militarized digital voltmeter developed by Kintel was designed with the digital voltmeter and digital readout in a single package. Since all control functions were provided by the automatic test system in which the unit

TABLE IV

Environmental Design Goals For Kintel Militarized Digital Voltmeter

Although final tests have not been completed, information derived from evaluation of preliminary instruments, and subsequent design improvements indicate that these specifications can be met or exceeded.

Radio Interference Suppression: The Model 412 shall comply with the requirements of MIL-1-6181.

Humidity: The equipment shall be capable of operating with a relative humidity of 95 ±5% at a temperature up to +83 F and thirteen (13) grains per cubic foot up to +125 F. The equipment shall be capable of withstanding storage at a relative humidity of 95 ±5% at a temperature of +160 F.

Operating Temperature: The equipment shall be capable of operating in an ambient temperature at sea level down to −10 F and up to +125 F. At a 6000 foot altitude it shall be capable of operating at a temperature of +80 F plus solar radiation.

Storage Temperature: The equipment shall be capable of withstanding storage without damage at temperatures ranging from −80 to +160 F.

Altitude: The equipment shall be capable of operation at any altitude from sea level to 6000 feet and shall be capable of withstanding storage and transportation at any altitude from sea level to 50,000 feet.

Vibration: The equipment shall be capable of withstanding conditions of vibration when the frequency is varied linearly from 2 to 27.5 cps and returned to 2 cps in a ten (10) minute period and then is varied linearly from 27.5 to 52 cps and returned to 27.5 cps in another ten (10) minute interval. The above twenty (20) minutes of vibration shall be considered one cycle and each chassis shall be vibrated for one cycle in each of three mutually perpendicular planes. The rate of change of frequency shall not exceed one (1) cps per second. The double amplitude excursion during each ten (10) minute period shall be as specified below:

Frequency	Double Amplitude Excursion
2 cps to 27.5 cps	0.125 inch
27.5 cps to 52 cps	0.036 inch

Shock: The equipment shall be capable of withstanding the shock tests as specified in the paragraph entitled "Shock Tests, Procedure VI, of MIL-E-4970".

Sunlight: The equipment shall be protected, insofar as possible from the deteriorating effects of solar radiation by the use of protective materials of opaque coatings or both. Coatings shall be used wherever possible to prevent glare from sunlight.

was installed, no control panel was required. The present model consists of the basic digital voltmeter and a separate unit housing the digital readout and remote controls. While this arrangement is probably the most useful for general applications, the unit can be packaged in virtually any other configuration desired.

The digital voltmeter is constructed as a single package with internal segregation of non-related circuits on individual, ruggedized, plug-in assemblies. These assemblies are constructed on etched circuit boards with all components of appreciable mass bolted in place. Installed, they are firmly supported on all four sides.

The overall packaging technique is unique in many respects. Physically the instrument consists of a "box-within a box", with the inner box being a heavy duty chamber containing the subassemblies which are most vulnerable to environmental conditions. This enclosure is heavily constructed, well sealed, and contains a desiccant capsule. Electrically, the instrument consists of three enclosures—the outer case, the sealed chamber, and an inner shielding system. These three are combined in an elaborate guarding network that provides an exceptionally high degree of isolation, permitting normal operation in the presence of high common mode potentials.

Importance of this isolation cannot be over emphasized. Installations which have any appreciable distance between the source and the system will invariably have sufficient common mode potentials present to seriously affect the accuracy and stability of standard commercial instruments. Unfortunately, a good deal of confusion exists as to the meaning of common mode rejection, floating operation, etc. Therefore it is important to view claims of this nature somewhat skeptically when they are not substantiated by a description of the actual tests performed. Environmental design goals are listed in Table IV.

The basic principle of operation for Kintel's Model 501 and Model 412 involves a Wolff-bridge, an internal standard, and a successive comparison of the bridge voltage with the unknown voltage. The comparators are choppers which compare a known sample of the bridge-divided reference voltage against the unknown input. Any difference between these two signals is processed into a "drive" pulse which alters the bridge ratio. Hence, when no more difference is observed between the unknown input voltage and the divided reference, no further pulses are generated and a balance is attained. The number of steps required to find the balance in this way represents the actual voltage of the unknown signal. This voltage is displayed on a single-plane projection-type readout. In their Model 863BR, the electronic digital voltmeter, a somewhat different principle is involved. Here the chopper grounds the unknown voltage between resistive elements of a voltage divider. In this model the resistors for the voltage division are switched by a series of diodes until the mid-point of the voltage divider is at ground level. Then, no further error signals are obtained.

Cubic Corporation provides a wide range of digital instrumentation based upon the digital voltmeter and a variety of auxiliary apparatus. These instruments include the usual devices for dc and ac voltage measurements and resistance measurements. The unit construction of digital instruments simplifies systems development to fit specialized requirements. Sophisticated systems can be "customized" with standard units. Additional units can be added to increase system capabilities. Some of the specialized devices are a dc voltmeter unit of the self-balancing potentiometer type, a control unit which includes power supply, precision reference, and difference amplifier for the voltmeter. This control unit powers all units in a Cubic digital system. A preamplifier amplifies voltages from ±10 microvolts for reading by the voltmeter. Its accuracy is ±0.01%, and its gain is 10. An ac converter accepts ac input voltages and converts them to dc to be read by the voltmeter. Additional Cubic standard models are used for ratio measurement, scanning instrumentation, time display instrumentation, and printer control units.

Electro Instruments, Inc. has developed a line of sixteen different digital multimeters to permit selection of the exact functions required to minimize equipment cost. These analog to digital converters are all electronic, featuring totally transistorized circuitry, with consequent high reliability in a minimum size and weight package and low power consumption. Components are mounted on plug-in printed circuit cards for ease of preventive and operational maintenance.

The entire line of instruments exhibits a combination of high input impedance (1000 megohms on dc voltage and dc ratio measurements), 4 digit accuracy, automatic ranging, automatic polarity, and high speed. A pre-regulated zener diode bridge with the diodes in a temperature-stabilized oven develops an output reference with temperature stability and drift characteristics better than 0.005%, according to the manufacturer. Necessary control logic is available at rear panel connectors for external control. Models with electrical outputs and print control capabilities operate directly in multi-point scanning and print-out data logging systems without additional circuitry or auxiliary equipment.

A sensitivity control is provided on each instrument to overcome unusual noise conditions, giving at the same time a qualitative measurement of the noise present.

A unique development by **Electro Instruments, Inc.** is their true rms digital voltmeter. This instrument incorporates a temperature stablized diode network operating on the square law principle to yield a true rms voltage reading regardless of the ac waveform or dc. The manufacturer claims accuracy of 0.1% for crest factors up to two for frequency inputs from 50 cps through 5 kc, as well as dc. The instrument can typically read to this accuracy distorted sine waves, square waves, and triangular waves. Typical balance time is 3 seconds, with a maximum of 5 seconds per range.

A completely transistorized digital voltmeter by **Electronic Associates, Inc.** features high speed and high accuracy. Their Model 26.070 has a 4 decimal digit readout to an accuracy of ±0.01% of full scale and 1 digit, with an average frequency of 200 readings per second. Polarity indication is automatic. Decimal and binary coded decimal voltages are available as an electrical output. Special output codes, higher conversion speed, and remote range control are available, as well as a variety of accessories including an ac-dc converter, high speed printer, input commutator systems, and special output programmers.

Epsco manufactures a fast, particularly compact multi-purpose multi-output digital volt-ohm meter, consisting of a fully-transistorized analog-to- digital converter and digital display. The basic converter is a dc, ac, and resistance to decimal digits converter, making up to 100 independent conversions per second. The unit measures bipolar dc and ac voltages from 1 millivolt to 1000 volts, and resistance from 1 ohm to 1.0 megohms. The accuracy is ±0.1 percent for dc measurements and ±0.5 percent for ac and resistance measurements. Output is displayed within the instrument as a three-decimal digit readout plus an overflow digit with the sign function and decimal point auto-

matically displayed.

The unit sweep or ramp method of conversion is used. A linear sweep is generated internally under the control of a timing source and is compared with the unknown data voltage and with ground. Oscillator pulses are gated on by the first of the two comparison pulses and gated off by the second. These pulses are accumulated in a decimal counter. This counter output is decoded and presented visually as an in-line, in-plan decimal display. The sign of the in-put voltage is automatically determined by the order in which the two comparison pulses occur. For a resistance measurement, the unknown resistor becomes the feedback resistor of the in-put chopper-stabilized operational amplifier. An internal 10 volt reference voltage is applied across a precision input resistor to generate a test current through the unknown resistor. For ac measurements, the peak input signal is detected, digitized and displayed as 0.707 of the peak value.

Beckman/Berkeley Division, of Beckman Instruments, Inc. markets a popular digital voltmeter in which a hundred kilocycle signal is counted for an interval proportional to the input dc voltage, using the precision ramp function to establish the interval as described above. This modestly priced medium accuracy portable unit is all electronic, provides a binary coded output, and permits measurements to 150% of full scale.

Electro-Logic Corp., applying stroboscopic readout techniques to an analog voltage balancing system, has developed a digital unit with 0.4% accuracy at the low cost of $295. This design generates a voltage ramp function by continuously rotating a long-life conductive plastic potentiometer energized by a dc reference voltage. Coupled to the shaft of the pot is a drum with a series of 250 numbers at equal intervals along a transparent film section indexed to correspond in magnitude with the pot's voltage ramp function. The numbers show through small holes in the drum surface.

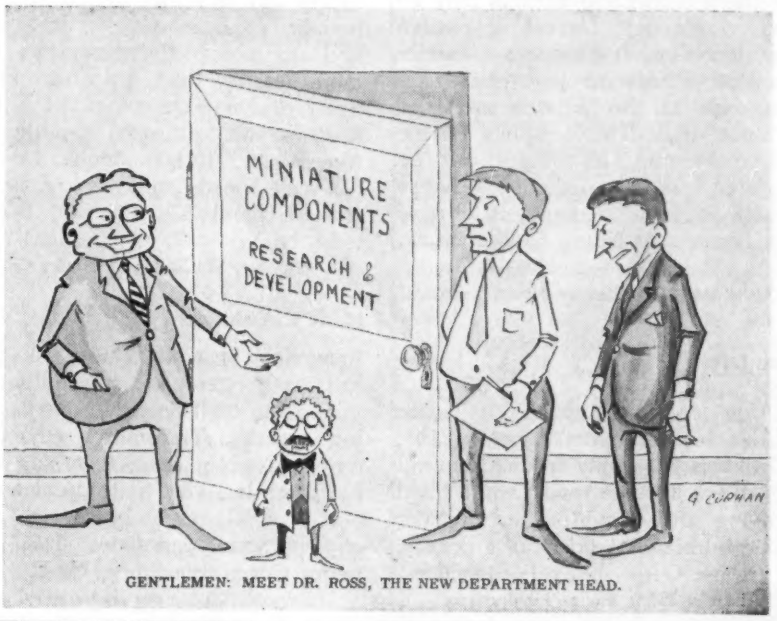
A measuring circuit which continuously compares the pot's wiper voltage with the unknown voltage triggers a strobe lamp circuit when the two voltages are equal. The lamp circuit flashes two strobe lamps which illuminate the number on the drum corresponding to the magnitude of the balanced voltage when the number is aligned with a projection lens.

Since the comparison is made once for each revolution, the strobe lamps "fix" or stop the number corresponding to the unknown voltage. The number is then optically enlarged and projected onto a ground-glass screen on front of the instrument. At a drum speed of 24 rpm, the apparatus produces an apparently steady number indication.

A major factor in the development of this instrument was the choice of a conductive plastic sweep potentiometer, manufactured by Markite Corp. Because of the high rotational speed required by the design, performance of a conventional wire-wound pot would degrade due to wear causing linearity problems within a relatively short time. Conductive plastic resistance track presents a hard, smooth, uninterrupted surface to withstand wear from wiper contact at high speed.

Under life test in this system, the conductive plastic pot has maintained specified accuracy after 130 million revolutions.

END OF COMPONENTS DIGEST #18



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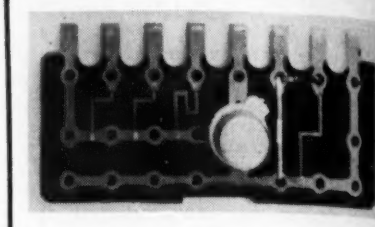

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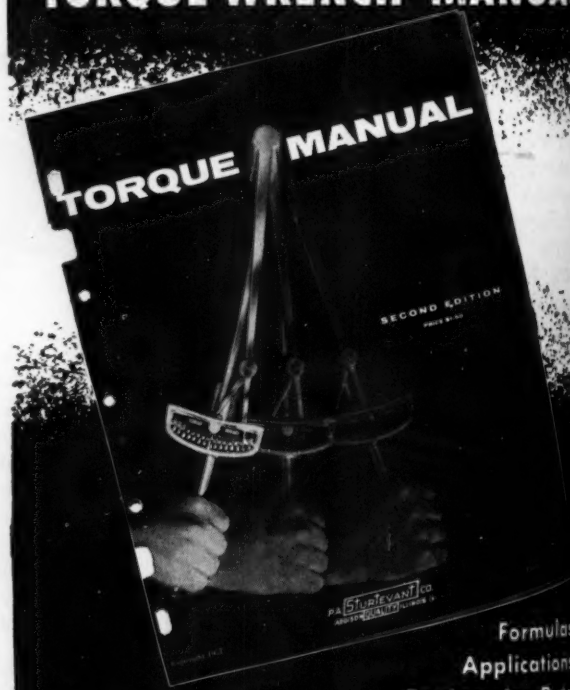

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Series of power supplies offers outputs of 6, 12, 18, 24 and 28 volts at 2 amps, each variable to ±1 volt. Ripple is 5 mv, peak to peak, with line regulation of 5 mv and load regulation of 30 mv max. Response time is 50 microseconds or less, no load to full load. Of full semiconductor design, the units operate with an input of 105 to 125 volts and a frequency range of 60 to 400 cps. Physical dimensions are 8½ x 8⅜ x 3 in. high and two units may be mounted side by side on a 3½ x 19 in. rack panel or as a subassembly on either an 8½ x 8⅜ in. or 8½ x 3 in. space. Elasco, Inc., Roxbury, Mass.

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Measuring 6″ x 6″ x 11″ and weighing 12 lbs., a 20 w 60 cps general purpose servo amplifier operates on both dc and ac input signals. A 100 mv input causes a 115 v, 60 cps output to rated load. Unit is self protecting from overload due to excessive input signal. Input impedance: over 300 k for signal input and 25 k for tach input; output impedance: less than 100 ohms; noise output: negligible; waveform shows less than 10% harmonic distortion. Gain, zeroing, output, level and tach controls are provided, plus a control to adjust an internal damping network for dc signals. K-F Products, Inc., Denver, Colo.

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Silicon Diodes

Hermetically sealed in fused-glass packages, 35 silicon diodes are impervious to moisture and contaminants and meet and exceed MIL-S-19500B. Reliable operation up to 200°C is claimed for the 0.265-inch by 0.105-inch diodes. In four categories, the units are: high-conductance, high-resistance; high-conductance, high-conductance, general purpose; and general purpose. Raytheon Mfg. Co., Needham, Mass.

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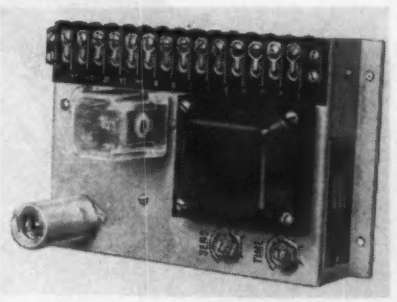

Photoelectric Scanner Relay

Time-response adjustment that permits a light-beam to be interrupted repeatedly for intervals shorter than the selected delay-time makes a photoelectric scanner relay suitable for such uses as monitoring the movement of parts through handling systems. Provides positive indication when parts fail to feed or when they jam up on a moving conveyor. Delay can be as little as 50 milliseconds or up to 1½ seconds. Various light-source/photocell combinations permit choice of scanning distance and use of direct light or a proximity sensor. Farmer Electric Products Co., Inc., Newton Lower Falls, Mass.

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BOOK REVIEWS

Book Computer

Kirk Finley Carlsten
Karsten Gene Hellebust
900 pages. $15.00
Metron Instrument Co.
432 Lincoln St., Denver 3, Colo.

With a Book Computer, you can multiply and divide to six significant figures. The tables are a photographical reproduction of the output of a digital computer. Calculations are said to be five times faster than log tables and more accurate than a slide rule. Also, square and cube roots, reciprocals, common logs and products of (n) x π and (n)^2 $\pi/4$ are listed for all numbers from 100 to 999. The Book Computer is sold on a ten day approval-basis.

Handbook of Chemistry and Physics, The 42nd Edition

3400 pages, $12.00
The Chemical Rubber Co.
2310 Superior Ave., Cleveland, Ohio

Over 200 prominent collaborators, who are recognized in their own science research fields, have contributed to make up the 3400 pages of latest data classified under five handy indexes in this new edition of the well-known handbook. New tables include: Diffusion of Metals, Interplanetary Orbits, Standard Types of Stainless Steel, to mention a few. Among the revised, expanded and up-dated data are: Atomic Weights, Trade Names of Plastics, Nuclear Spins, and many others.

Applied Engineering Mechanics

Alfred Jansen and Harry H. Chenoweth
409 pages, $6.50
McGraw-Hill Book Co.
330 W. 42nd St., New York 36, N.Y.

Book emphasizes the use of scientific reasoning rather than complicated mathematics for solving engineering problems. Easy to read, easy to understand and use, it is also suited for brush-up work. The volume proceeds from easy to difficult phases of engineering mechanics, clarifying the principles advanced with numerous illustrations. Covering 151 separate technical topics, this revised second edition helps you to a more thorough and practical knowledge of basic engineering fundamentals and demonstrates the application of these with easily followed examples. More than 110 problems, with 50% of the answers supplied, help you test and master the theories advanced. This book gives you the steps to take in solving scores of technical problems, and provides workmanlike and effective standard practice.

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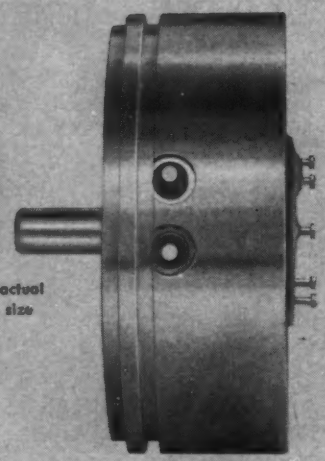

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CIRCLE NO. 75 ON INQUIRY CARD

For Your Literature File
NEW CATALOGS

Most of these catalogs contain complete specs, mounting configurations and other important details associated with the application of the products described. For your free copy of the catalogs listed on this page, enter the appropriate number of the item on the Inquiry Card.

Copper Alloys 964

"Metals for electrical and electronic apparatus" includes a check list for electrical conductivity ratings of 56 copper alloys and a listing of mill shapes for each alloy (sheet, rod, wire, tube) and typical uses based on physical and mechanical property characteristics. Alloys are divided into nine groups: coppers, brasses, non-leaded brasses, tin brasses, phosphor bronzes, cupro nickels, nickel silvers, silicon bronzes and aluminum-silicon bronzes. (8 pp.) Bridgeport Brass Co., Bridgeport, Conn.

Capacitors 966

Complete line of capacitors includes types that comply with Mil C-14157B. A mylar film dielectric type in a plastic case is said to be attractively priced. (4 pp.) Victoreen Instrument Co., Chicago, Ill.

Motors 965

Brochure describes ac and dc motors ranging from fractional hp miniature motors to integral 25 hp units. Examples of ac phasing capacitors and radio frequency interference filters are included. Airesearch Mfg. Co., Los Angeles, Calif.

Telephone Relays 968

Chart shows all of the electrical and mechanical characteristics of seven basic types of relays as well as coil data and available enclosures. A nomogram in which operating speed can be calculated plus supplemental information such as speed, pressure conversion and temperature rise curves has been included. (4 pp.) American Machine & Foundry Co., Princeton, Ind.

Precision Connectors 967

Special designs and a description of crimp type removable contact connectors are given in addition to highlights and specs for printed circuit, miniature and power connectors. (8 pp.) DeJur-Amsco Corp., Long Island City, N.Y.

Synchronous Motors 960

Technical characteristics, specs, ratings and outline dimensions are given for 50, 150 and 250 ounce-inch synchronous motors that feature instant starting, stopping and reversing. Conventional, militarized and explosion proof types are offered with or without planetary gear speed reduction assemblies. All have a basic shaft speed of 72 rpm at 60 cycles and can be used as constant speed ac motors or as dc stepping or incremental positioning devices. (8 pp.) Superior Electric Co., Bristol, Conn.

Wirewound Potentiometer 962

Twenty-eight standard models of linear, non-linear and sine-cosine potentiometers, ranging in size from ¾" to 5" dia., are classified in terms of case design, clamp band configuration and mounting. Phase-shifters, solenoid detent spring return mechanisms, cam-actuated micro switches and electro-magnet clutches and brakes can be incorporated into these units. (6 pp.) Fairchild Controls Corp., Hicksville, N.Y.

Rotary Switches 969

Information on 3072 hermetically sealed rotary switches includes complete control and performance data, environmental conditions, duty cycles, voltage codes, and approximate "hold-in" resistor values. (13 pp.) Ledex Inc., Dayton, Ohio.

Magnetic Reed Switches 970

Hermetically sealed for use in dry or wet atmospheres, switches will operate in any position. Included are data on actuation methods and mechanism (mechanical and electro-magnetic), test charts for life expectancy, method of code identification, and a permanent magnet chart with typical make and break contact distances. (6 pp.) Hamlin, Inc., Lake Mills, Wisc.

Drafting Pencils 971

Pencils specially designed for work on drafting film; for color coding on tracings; and for making temporary work notes on drawings are included in a comprehensive selection of drafting pencils, leads and holders. (24 pp.) J. S. Staedtler, Inc., Hackensack, N.J.

Silicones 954

More than 25 applications for silicones in military and commercial aircraft, in missiles and in ground support equipment are described. Silicone products such as fluids, rubber, potting materials, sealants, and protective coatings are covered. (8 pp.) Dow Corning Corp., Midland, Mich.

Test Instruments 955

Complete line of integrated instruments for automatic measurement of sound, vibration and strain are covered. Included are accelerometers, analyzers, voltmeters, deviation bridges, oscillators and many other devices. (24 pp.) B & K Instruments, Inc., Cleveland, Ohio.

FHP Motors 956

How a spectrophotometer is used to make chemical analyses and how a high-speed electronic process can translate computer language and print or display information at the rate of 20,000 letters, numbers and symbols per second, are described as applications of FHP motors. (4 pp.) Bodine Electric Co., Chicago, Ill.

Back-Up Rings 957

Designed to greatly increase O-ring seal life, contour shaped back-up rings are moulded in one continuous circle. Eliminates O-ring extrusion, pinching or biting and will not "collapse" or cold flow into open groove areas. (6 pp.) Parker Seal Co., Culver City, Calif.

Cathode Ray Tubes 961

Sixty five industrial cathode ray tube types and seven single and dual-gun, recording storage tube types are described in detail. In a complete and simplified chart, types offered by all manufacturers are listed in numerical order, indicating the physical and electrical characteristics, typical applications and operating conditions of each. (4 pp) Raytheon Co., Newton, Mass.

ADVERTISERS' INDEX

ADVERTISERS	Page Number
Indiana Steel Products *Div. of Indiana General Corp.*	54
Kearfott Division *General Precision, Inc.*	33
Kinney Vacuum Division *The New York Air Brake Co.*	21
Kollmorgen Corp. *Inland Motor Corp. of Virginia*	22
Litton Industries *Litton Systems, Inc.*	61
Magnetec Corp., The	71
Micro Systems, Inc. *Div. of Electro-Optical Systems, Inc.*	18
Miniature Precision Bearings, Inc.	28
Mosinee Paper Mills Co.	31
National Pneumatic Co., Inc. *Holtzer-Cabot Division*	66
National Radio Co., Inc.	36
New York Air Brake, The	21
Non-Linear Systems, Inc.	41, 42, 43, 44
Ogilvie Press, Inc.	25
Ohio Carbon Co., The	77
PIC Design Corp.	37
PSP Engineering Co.	84
Pace Engineering Co.	49
Plastic Capacitors, Inc.	61
Raytheon Co. *Equipment Div.*	Cover 3
Revco, Inc.	71
Sel-Rex Corp.	72
Sigmund Cohn Corp.	75
Singer-Bridgeport *Div. of The Singer Mfg. Co.*	78
Southwest Products Co.	83
Sturtevant Co., P. A.	76
United Aircraft Corp. *Norden Div., Milford Dept.*	19
United Electric Controls	82
Universal Relay Corp.	49
Valcor Engineering Corp.	29
Waltham Precision Instrument Co.	57
Wurlitzer Co., The	79

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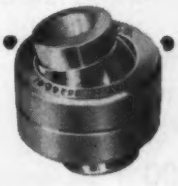

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3	Bronze Race and Chrome Steel Ball	For types operating under normal loads with minimum friction requirements.
4	"Dyflon"® Plastic Alloy Inserts. CRES Ball and Race. Chrome Alloy Steels.	For types operating under rotational, high radial loads and long cycle life where lubrication is impossible.

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CIRCLE NO. 73 ON INQUIRY CARD

For Your 3-Ring Binder

NEW DATA SHEETS

Most of these data sheets contain complete specs, mounting configurations and other important details associated with the application of the products described. For your free copy of the data sheets listed on this page, enter the appropriate number of the item on the Inquiry Card.

DC Relays 919

Up to 50% adjustment of the drop-out-to-pull-in ratio for marginal relay operations is provided by sensitive dc relays. Resistant to 50g shock, they also withstand vibration up to 500 cps at 10g. Standard contact rating is 2 amps at 29v dc or 1 amp at 115v ac. Weighing 2 oz. maximum, the relays measure ¾" dia. and 2-5/64" overall. Allied Control Co., Inc., New York, N.Y.

Time Delay Relays 917

Solid state electronic timing devices provide delay periods form 0.020 to 300 seconds, with delay-on-drop-out. Units require a continuous source of 28 vdc input power plus a 28 vdc control voltage. AC relays provide delay periods from 0.050 to 300 seconds, with delay action occurring on pull-in. Tempo Instrument Inc., Hicksville, N.Y.

Socket Cap Screws 648

Dimensional standards, concentricity limits, and threading dimensions are given for socket cap screws. Screw's large head size (1½ times body diameter) distributes the load over a large area, often eliminating the need for a washer and providing a greater holding power. The Bristol Co., Waterbury, Conn.

Environmental Sensing Devices 649

Three technical data sheets describe two absolute air pressure switches and one gas density switch. Used primarily as control or warning devices, the switches monitor pressures or densities of gas or vapors either in sealed containers or in open systems. Newark Controls Co., Bloomfield, N.J.

Vibrachopper 650

In a solid state vibrachopper, the design of the low level chopper eliminates the necessity of supplying a ac driving source at a fixed frequency. A self-contained adjustable-frequency vibrator drives the chopper under optimum conditions. Activation is induced merely by supplying a dc voltage with low power drain. Solid State Electronics Co., Sepulveda, Calif.

Plastics 653

Brochure discusses the application of value analysis and its results to a series of different products in the electrical, electronic, and mechanical fields. Examples explain how the use of specific plastic materials improve design and utility, cure processing and assembly time and reduce cost as high as 75%. Spaulding Fibre Co., Tonawanda, N.Y.

Precision Differentials 906

Subminiature solid shaft differentials with a guaranteed backlash rating of 5 minutes max. are of all stainless steel construction and contain double ball bearing suspension for minimum torque. Hollow shaft differentials with a unique integral V-block clamp design for positive locking and minimum space envelop are said to be 30% smaller than other available units. Backlash rating is 5 minutes max. Empire Flight Components, Inc., Bellmore, N.Y.

Microreproduction System 901

Folder discusses the new standards and specs of the Defense Department's engineering data microreproduction system. Aperture cards that form the basis of the system are explained and illustrated. Minnesota Mining and Mfg. Co., St. Paul, Minn.

Power Supply 902

Low cost transistor regulated dc power supplies have an output voltage range of 4 — 32 v dc with current ratings from 1.5 to 15 amps. Rated input is 105 — 125 v ac, 60 cycles, single phase. Regulation is within ± ½% for line and load changes and ripple does not exceed 5 mv rms. Opad Electric Co., N.Y., N.Y.

DC Magnetic Amplifiers 903

Low level magnetic amplifiers provide linear outputs of ± 7.5 volts dc with input signals in the low millivolt range. Units operate over a temperature range of —55 to +85 C and are used in complex data amplification and control systems. Transfer curves are included. Airpax Electronics, Inc., Fort Lauderdale, Fla.

Precision Potentiometer 904

Developed especially for high reliability applications, precision potentiometers continue to meet their original specs after 2,000 hrs of operation at 150 C. Standard resistance values range from 100 to 50,000 ohms with conformities of 0.14% if required. Terminals are guaranteed against any type of damage except the snapping of turrets which requires approximately 45 in. oz. torque. Carter Mfg. Corp., Hudson, Mass.

Potentiometers 910

Using only a pencil point you can set taps to ½ degree, save valuable man-hours and the need for special tapping tools on Accuracy's Inc. potentiometer. Settings can be changed by eye in 30 seconds for precision applications. Accuracy, Inc., Waltham, Mass.

Filters 912

Special purpose filters for telemetering, band pass, high and low pass, amplifier, discriminator and aircraft glide slope indicator applications are hermetically sealed, and meet MIL-F-18327A. Chicago Standard Transformer Corp., Chicago, Ill.

Computer Diodes 930

Employing a technological breakthrough in the formation of its junction, a gold-bonded computer diode is said to be at least ten times faster than any production diode ever offered. Its guaranteed recovery time of 0.5 nanoseconds is given only to accommodate the measuring limits of standard sampling oscilloscopes. In development tests, computer diode switched from ten milliamps forward current to minus six volts reverse voltage with less than 0.2 nanoseconds recovery time. Typical capacitance for the total diode: 0.7 picofarads. Rectification efficiency: 25% at 13.5 kmc. Hughes Aircraft Co., Newport Beach, Calif.

Resistors On a Reel 908

Purchase resistors by the yard or mile with newly developed "Reel-Packs". Reels facilitate storing, holding and positioning resistors for automatic feeding in automated assembly lines. Principal use at present is in printed circuit boards for computers, guidance systems and similar electronic equipment. Ward Leonard Electric Co., Mount Vernon, N. Y.